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REFERENCE

Lane, B. H., 1935, Suggestions to authors of papers submitted for publication by the United States Geological Survey: U. S. Geol. Survey, Washington, D. C. (For sale by Superintendent of Documents, Washington, D. C. 35c.)

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American Journal of Science

SEPTEMBER 1954

FISH CREEK PHACOLITH, NORTHWESTERN NEW YORK

R. V. DIETRICH

ABSTRACT. The Fish Creek intrusive mass is located in the Brier Hill quadrangle, northwestern New York. The mass, of an outcrop area of approximately 12 square miles, occupies a steeply plunging, nearly isoclinally folded syncline. The outcrop surface is a cross-section nearly perpendicular to the axis of the fold. The main part of the mass is a fine-grained, pink alaskite gneiss. Medium-grained, gray-green trondhjemite, which is regarded as a portion of the alaskite magma contaminated by impure marble, forms a discontinuous border facies. All intrusive contacts observed are with highly metamorphosed Precambrian Grenville series marble. The mass is considered to be a phacolith because: (1) it is generally concordant; (2) it occupies the trough of a syncline; (3) it has a general lenticular cross-section; and (4) it appears to have resulted from the consolidation of magma that was intruded syntectonically. Phacolithic emplacement is inferred because of marked thickening on the plunging nose of the mass and the presence of sheetlike inclusions within the alaskite. The lack within the Fish Creek mass of a systematic spatial arrangement of alaskite that is apparently undeformed, of alaskite that has a marked cataclastic texture, and of alaskite that has been recrystallized completely is thought to be corroborative because this arrangement appears to be explained more readily as a result of deformation during the consolidation of the magma than by subsequent deformation of the solid rock.

INTRODUCTION

Buddington (1929) presented the idea, then novel in American geology, that 14 Precambrian alaskitic bodies in the northwestern Adirondacks are phacoliths. He described five of the masses in detail and suggested that the other nine masses may be phacoliths on the basis of their petrography and outcrop pattern. The Fish Creek mass, one of the latter masses, has been investigated and described in detail by the writer (Dietrich, to be published). The main features of the mass and additional genetic considerations are presented here.

The mass is composed chiefly of alaskite gneiss, has a discontinuous trondhjemite border facies, and has local concentrations of sheetlike gneissic pyroxene-plagioclase inclusions. The body has been called the Macomb granite and considered to be a portion of the Alexandria bathylith by Cushing (1916, p. 18); it was named the Fish Creek phacolith by Buddington (1929, p. 52). "Fish Creek" is used in this report because the mass is on Fish Creek, whereas only a part of it is in the town of Macomb and its southernmost part is more than five miles northeast of the village of Macomb.

The Fish Creek alaskite mass is considered to be a phacolith because it is a generally concordant, lenticular body that occupies the trough of a syncline and because evidence suggests that the alaskite owes its origin to consolidation of a magma that gained its present position by syntectonic intrusion. These fill the qualifications established for the phacolith concept (see especially Harker, 1909, p. 77-78; Vogt, 1927, p. 136-185, 249-260; Buddington,

1929, p. 51-81; Stenzel, 1936), i.e., syntectonic (synkinematic) intrusion of magma along crests and/or troughs of folds in country rocks. They eliminate other types of igneous intrusive masses that would be most difficult to distinguish from phacoliths—folded laccoliths or sills and igneous masses that have intruded previously folded sediments.

GENERAL FEATURES

The Fish Creek mass has a total outcrop area of approximately 12 square miles. It has a U-shaped outcrop pattern and data from wells located between the arms of the U, i.e., wells that go through 80 to 115 feet of Potsdam sandstone into marble, show that this apparent shape is a true expression of the shape of the mass and not the result of a fortuitous erosion of overlapping sandstone. The outcrop surface is a cross-section nearly perpendicular to the axis of the mass. The mass occupies a syncline[1] that plunges steeply toward the northeast and has its axial plane dipping steeply toward the southeast (fig. 2).

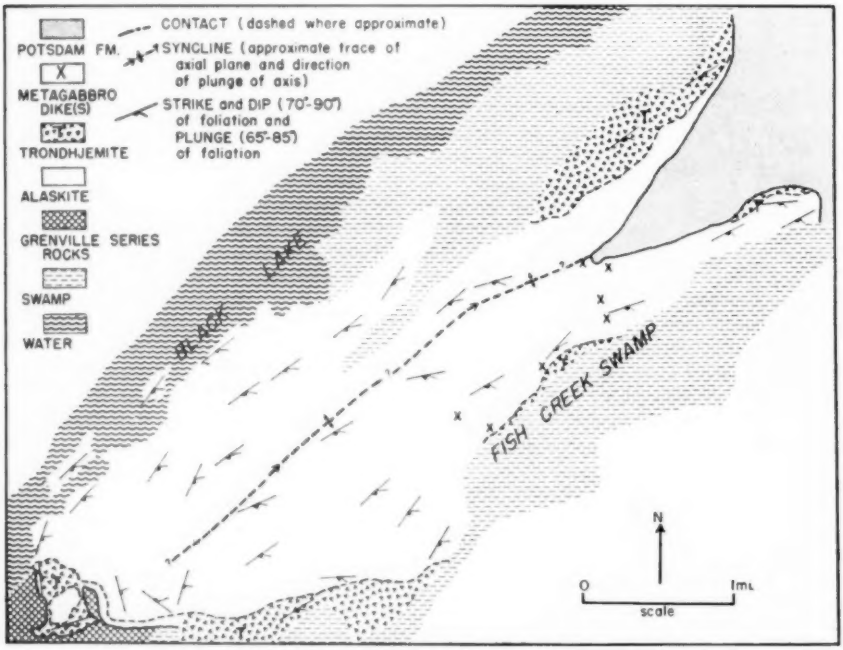


Fig. 1. Generalized map of the Fish Creek phacolith.

Structural relationships between the alaskite and surrounding Precambrian Grenville rocks cannot be determined definitely in many places because most of the contact is covered. However, similar orientation of minor struc-

[1] Syncline is generally defined as a fold with the younger rocks toward the center of the curvature. Because age relationships of different strata of the Grenville series are unknown, syncline is used here in its geometrical sense, i.e., a fold that is concave upwards.

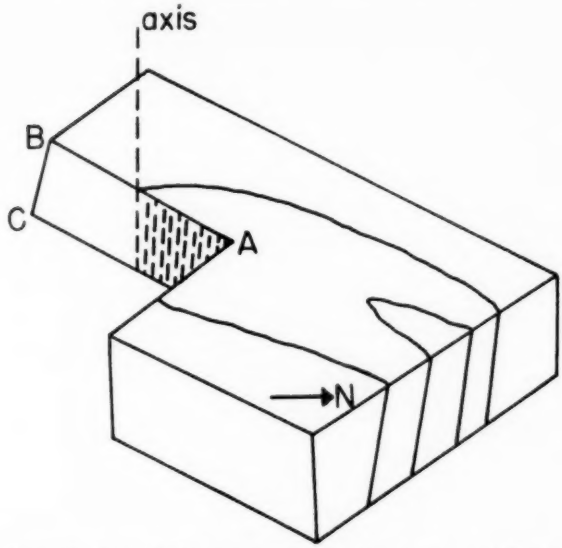


Fig. 2. Generalized block diagram of the Fish Creek mass. (ABC plane is foliation plane; dashed lines on this plane indicate lineation.)

tural features in the alaskite and in the Grenville rocks and the relationships between the two units at observable contacts suggest that the mass is generally concordant. Axes of nearly all minor folds in adjacent Grenville series rocks and of folded sheetlike inclusions within the alaskite gneiss are parallel to the lineation of the alaskite. Axial planes of most of these minor folds are parallel to the trend of the foliation of the alaskite. Where the contact of the alaskite gneiss with the Grenville series rocks can be observed, e.g., locally along the southern border of the mass, the marble is, except for minor divergences, concordant to the contact. The arrangement of tabular inclusions in the massive trondhjemite border facies and the overall shape of the mass corroborate the general concordancy.

The synclinal structure of the body itself is indicated by foliations and lineations of the alaskite and by parameters of the sheetlike melanocratic inclusions within the alaskite. The foliation, marked by parallel orientation of blebs of magnetite and grains of leaf quartz in the alaskite, is perceptible at all outcrops of the Fish Creek mass, with the exception of those of the trondhjemite border facies. Although the trend of foliation of the alaskite is nearly constant over the whole body, locally the strikes and dips of the planar elements differ within short distances. Most of the abrupt local changes occur near folded and fractured xenoliths where the foliation of the alaskite commonly deviates from the areal trend and is more nearly parallel to crenulations and broken edges of the inclusions. The general foliation in the alaskite apparently represents an axial plane foliation and is believed to have been formed in response to tectonic stresses. The foliation parallel to the sides and edges of folded and fractured inclusions is thought to be the result of effects

associated with magmatic flowage. Lineation, which is nearly constant over the whole mass, is in the plane of the foliation. It is expressed by parallel arrangement of grains of leaf quartz and by intersections between foliation planes and folded inclusions. The folded inclusions, most of which are in a zone that nearly bisects the mass, typically have their axes parallel to the lineation of the alaskite and their axial planes parallel to the foliation trend of the alaskite. On the basis of the attitude of the foliations and lineations, the body is interpreted to occupy a nearly isoclinal syncline that plunges steeply to the northeast and has its axial plane, which is marked by a zone of highly folded inclusions, dipping at a high angle to the southeast. The structure of the mass is, of course, more complicated than indicated on the schematic diagram (fig. 2) and the generalized map (fig. 1). Possible complications are described in another paper by the writer (to be published).

PETROGRAPHY

Alaskite that makes up the main part of the Fish Creek mass is a fine-grained, pink, hololeucocratic gneiss. Preferred orientation of leaf quartz, present at most outcrops, gives both planar and linear fabrics to the rock. Sporadic blebs of magnetite and plates of biotite are the only accessory minerals megascopically visible. Where present, they accent the gneissosity.

Thin-section investigations show that the mineral composition and fabric of the alaskite gneiss are different from place to place. Because there is an apparent relationship between fabric and mineral composition, the differences in mineral composition are believed to be manifestations of the relative amounts of cataclasis versus recrystallization that the alaskite has undergone. That the different types grade imperceptibly into each other and that the compositional differences, as indicated by their modes, are strictly mineralogic within nearly constant chemical composition are corroborative.

Modal analyses are given in table 1 of two of the heteromorphic variants of the alaskite that appear to be nearly end members in mineral composition.

TABLE 1

Modes of Two Heteromorphic Variants of Alaskite Gneiss from the Fish Creek Mass

(Numbers indicate volumes in percentages.)

	I	II
quartz	48	50
microcline	5	19
albite (An_{0-5})		26
antiperthite ($Ab_{85}Mi_{15}$)	47	
accessory minerals*	trace	trace

* The accessory minerals, which are completely lacking in some specimens, are biotite, sphene, apatite, and opaque minerals (magnetite and possibly a trace of ilmenite). Anatase, chlorite, kaolin, and sericite are sporadic alteration products.

Rocks of intermediate compositions are common in the mass. Specimens con-

taining perthite[2] and quartz have one of two distinct fabrics—typically, they are mainly cataclastic with or without some grains of recrystallized quartz; perthite and quartz in one section, however, show no evident cataclasis nor recrystallization. Specimens having discrete grains of albite and microcline with quartz are believed to represent a complete reorganization of the type containing microperthite and quartz; it is suggested that the discrete grains of albite and microcline represent a complete unmixing of the perthite and segregation of the components and that the quartz, present as leaves, has been completely recrystallized. Specimens of intermediate compositions have what

PLATE 1

A. Dimensions of inclusions. Horizontal surface.

B. Plunge of the mass. Horizontal surface showing folded inclusions that have been weathered more than the alaskite host, leaving that host in relief; viewer was facing eastward.

[2] Perthitic feldspars in the Fish Creek mass have a range of composition between albite, 45 to 58 percent and potassium feldspar, 55 to 42 percent. *Perthite* is used here for both the antiperthites and the perthites.

appear to be intermediate fabrics. The following represent a few of the diverse types from the mass (pls. 3, 4, 5):

(1) Panallotriomorphic quartz and perthite with some of the grains showing a tendency to be amoeboid; small, rounded grains of quartz occur in larger grains of the perthite and small, rounded grains of the perthite occur in larger grains of quartz; albite rims are present on the grains of perthite along quartz-perthite and perthite-perthite borders but in general are lacking along perthite-albite borders. The perthite is made up of albite approximately 58 percent and potassium feldspar approximately 42 percent.

(2) Cataclastic perthite and quartz with minor albite; this rock tends to have a mortar fabric.

(3) Cataclastic perthite and quartz with some recrystallized quartz.

(4) Differentially granulated perthite and completely recrystallized quartz; porphyroclastic augen of perthite occur within a matrix of granulated perthite and recrystallized leaf quartz. Some thin sections have many such augen of perthite; others have only a few.

(5) A mosaic of albite and microcline with large quartz leaves; a trace of perthite is present locally.

MAGMATIC ORIGIN OF THE ALASKITE

No glass of alaskitic composition has been found to occur associated with the Fish Creek mass, so it cannot be stated unequivocally that the alaskite ever existed as a magma. Different ideas concerning the origin of the alaskite can be resolved into two main hypotheses: a) the body resulted through transformation, in the solid state, of pre-existing rocks—granitization; or b) the body resulted from consolidation of mobile rock matter that consisted in part of a liquid phase with the composition of a silicate melt—a magmatic origin.

Some of the more notable features that must be explained by any hypothesis of origin for the alaskite are:

(1) The ratio of the thickness of the nose to the thicknesses of the limbs of the alaskite mass is greater than the ratio of the same parameters of folds involving adjacent Grenville rocks.

(2) Structural features shown in plate 2-B could result only from movements involving an extremely mobile material.

(3) The foliation of the alaskite wraps around some of the inclusions within it.

(4) Tabular inclusions within the alaskite typically are oriented parallel to the foliation of their alaskite host.

(5) Strikes and dips of linear and planar elements of the alaskite gneiss differ within short distances locally.

(6) Threadlike fingers of alaskite material penetrate a few inclusions along their foliation planes.

(7) In some places, tabular inclusions that are highly folded lie between those that are relatively uncontorted.

(8) Some inclusions lie with their foliation athwart the foliation of the alaskite.

(9) A few inclusions do not have their foliation parallel to either their own borders or to the foliation of the host alaskite.

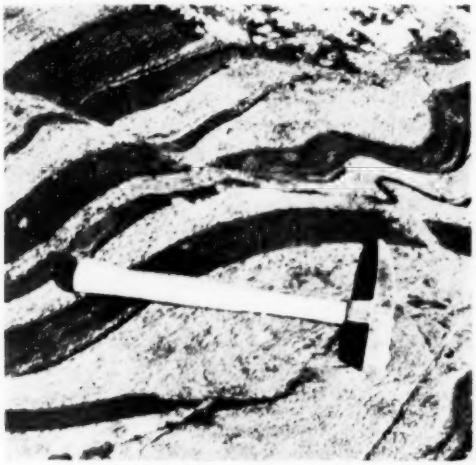
(10) Most inclusions have angular shapes.

(11) Most contacts between inclusions and the alaskite host are "knife edge" in sharpness; this is evident in both hand specimens and thin sections.

(12) Alaskite that is apparently undeformed, alaskite that has a marked cataclastic texture, alaskite that has been recrystallized, and alaskites with intermediate textures occur with no apparent systematic spatial arrangement within the mass.

PLATE 2

Some structural relationships of the inclusions.



A. Folded and fractured inclusions.

B. Fractured inclusions.

(13) The alaskite contains a notable percentage of perthite composed of nearly equal amounts of potassium and sodium feldspars (K-feldspar—55 to 42 percent; Na-feldspar—45 to 58 percent) and/or discrete grains of albite and microcline.

(14) Metamorphism of the contact type occurs spatially associated with the mass.

(15) The alaskite mass has some crosscutting relationships at its contact.

(16) Pegmatite and aplite bodies show a peripheral association with the alaskite mass.

(17) At least 14 bodies of this type, i.e., bodies composed of alaskite and structurally restricted to the crests or troughs of folds, are present in this region.

The first seven listed features indicate that the alaskite was very mobile during at least one period of its formation. This mobility could be accounted for by a magma or by the granitization of a previously highly plastic rock. The fact that the ratio of the thickness of the nose to the thicknesses of the limbs is greater for the folded alaskite body than the ratio of these parameters of folds involving nearby marble (1), however, would necessitate the granitization of a rock that was even more plastic than Grenville marble. No rocks of the Grenville series that appear to have been more mobile under deforming forces than the marble have been found to occur within this general region. A magma probably would have had the requisite mobility to account for this feature.

Relationships between the alaskite and its inclusions can be discerned rather easily because both horizontal and vertical exposures are abundant. The inclusions are thin sheets that are typically parallel to the foliation of the alaskite and generally have an internal gneissosity parallel to their margins. The sheets range from less than an inch to a few feet in thickness, are up to many rods in length, and appear to have extensions in depth comparable to their lengths along the strike. Most of the sheets have sharp contacts with the alaskite, although locally they are partially assimilated. The alaskite immediately adjacent to those with sharp borders is identical in composition to that of nearby alaskite that contains no inclusions; xenocrysts of hornblende and/or pyroxene are commonly present in the alaskite near assimilated inclusions. Only sporadic inclusions maintain their integrity for more than a few feet. Typically, the inclusions are broken, and alaskite, commonly pegmatitic, fills the intervening spaces. Although some broken ends show evidences of corrosion, most are unaltered fracture surfaces. Most of the fractured inclusions lose their apparent identity within short distances; some, however, because they are members of distinctive sequences, can be traced for great distances along their strikes, even where they have been broken and separated.

At some outcrops, individual highly contorted sheetlike inclusions occur between other sheetlike inclusions that are nearly straight or only slightly bent. Both types are typically fractured. Locally the foliation of the alaskite wraps around the fractured ends of the inclusions. The presence of the highly contorted sheets that are also fractured suggests that the relative rigidity of the inclusions differed temporally. The presence of contorted sheets between rela-

tively unfolded sheets suggests notable freedom of movement among the different inclusions. Other structural relationships, such as those shown in plate 2-B also indicate that there was great freedom of movement among the different inclusions and that even restricted zones were affected by distinctly different movements that were out of harmony with each other. As is apparent in this photograph, shortening was the result of the relative movements involving the thinner inclusion after it was fractured and its parts initially separated, whereas lengthening was the result of the relative movements involving the thicker inclusion after it was fractured. The movements indicated by the field evidence appear to have been similar to those found in flowing fluids.

The inclusions in the axial plane zone of the syncline are of special interest. Although there is a parallelism between the axial planes of the folded inclusions and the general foliation of the alaskite and a general parallelism between the axes of the folded inclusions and the lineation of the alaskite, many inclusions in this zone have their foliation athwart that of the alaskite and locally adjacent inclusions do not approach parallelism either of their shapes or of their internal foliations. Also, a notable number of the inclusions of this zone do not have their foliation parallel to their long dimensions. The presence of inclusions that lie with their foliation athwart the foliation of the

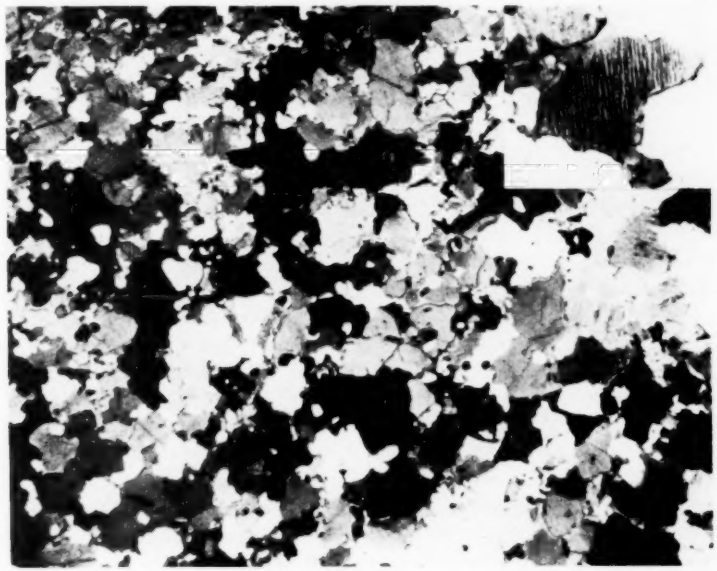


PLATE 3

Panallotriomorphic quartz and microperthite (x 8). Inset, upper right, shows relationships within the individual perthite grains more highly magnified (x 30).

alaskite imposes the necessity for at least two periods of foliation formation; this could be accounted for under the magmatic hypothesis by intrusion of a magma, that solidified to a gneissic rock, into a foliated sequence of rocks.

If, however, the alaskite had been formed by granitization, at least two periods of metamorphism would be necessitated, the latter of which would have had to have been strong enough to initiate a new or different foliation in one member and yet not strong enough to efface a previously formed foliation in the other member. It might be suggested that this set of conditions is not necessary because the inclusions might represent dismembered sills and dikes rather than foliated metasedimentary rocks; if this were true, however, the foliations in the inclusions would represent relict flow foliation and typically would be parallel to the borders of the tabular sheets; the presence of inclusions having their foliation at an angle to their margins and also at an angle to the foliation of the alaskite precludes this origin for at least some of the inclusions, and thus some relationships are present that would require at least the two periods of metamorphism. This especially complicates any suggestion that the mass resulted from granitization because it is the alaskite that has an axial plane foliation whereas the foliations of the included pyroxene-amphibole-plagioclase rocks commonly deviate from this trend. Consideration of the present degree of preferred orientation of constituent minerals in the host alaskite and in the included rocks suggests that the included rocks are more susceptible to induced foliation than the alaskite is.

Concerning the fabrics of the alaskite (10), none has a fabric that can be called unequivocally protoclastic. However, the presence of the different fabrics with no obvious systematic spatial arrangement within the mass may suggest that the deformation took place during consolidation of an at least partly mobile material. Under this interpretation, the cataclastic rocks might represent the results of deformation of consolidated portions of the magma; the recrystallized rocks, consolidated portions of the magma that were deformed in the presence of fluids or while hot, the fluids or higher temperature promoting recrystallization; the alaskite having a panallotriomorphic fabric without traces of either cataclasis or recrystallization, a portion of the magma that consolidated in zones sheltered from deformation, or a portion of the magma that consolidated after the main deformation; and the rocks having intermediate textures, intermediate conditions. The relative time of consolidation of the magma with respect to the period of effective deformation would have been the only control, and it is therefore necessary only to assume that different parts of the magma consolidated and cooled at different times from other parts. If, on the other hand, the fabrics are considered to represent deformation of solid rock, very localized forces of notably different magnitudes would be necessary to account for the differences.

If it is supposed that the perthite in the Fish Creek alaskite was formed by unmixing of an originally homogeneous alkali feldspar rather than by replacement or some other process(es), then the presence of perthite consisting of nearly equal amounts of potassium feldspar and sodium feldspar (13) indicates that the alaskite consolidated at a temperature of at least 650°C. (Bowen and Tuttle, 1950, p. 501-502, 510-511; Tuttle, 1952, p. 112). The extremely low calcium content of the alaskite (Tuttle, 1952, p. 117-119), comparison of the features of the perthites in the alaskite with features commonly shown by structures known to have formed by unmixing from origin-

ally homogeneous solids (e.g., pearlitic structures in some alloys), and consideration of previous discussion (Perrin and Roubault, 1953; Tuttle, 1953) warrant this supposition in the opinion of the writer. The alaskite made up of discrete grains of microcline and albite is interpreted as the result of unmixing carried to its ultimate limit, i.e., complete elimination of one feldspar from the other. This unmixing of a once homogeneous alkali feldspar into perthite and locally into discrete grains of albite and microcline may have been promoted by prolonged heating below the temperature of stability of the homogeneous feldspar (Bowen and Tuttle, 1950; Tuttle, 1952), by stress (Phemister, 1926, p. 25; Larsen, 1938; Buddington, 1939, p. 329; Chayes, 1952), by slow cooling (Chayes, 1952, p. 293), or possibly by a combination of processes. It appears likely in the light of the suggested mode of emplacement of the mass and of post-emplacement events that the alaskite was in a zone where prolonged heating or slow cooling would have obtained and also that it was affected by tectonic stress(es) both during and after emplacement. That the feldspar was at or near 650°C. at one time in its evolution and that actual rocks and synthetically prepared mixtures similar in composition to the Fish Creek alaskite begin to melt at 655°C. and 4000 bars water vapor pressure (Tuttle, 1953) are strong evidence in favor of a magmatic origin for the Fish Creek alaskite.

The shapes and contacts of the inclusions, the metamorphism spatially associated with the mass (14), the local crosscutting relationships (15), and the peripheral arrangement of pegmatites and aplites (16) are suggestive of an igneous origin for this mass, in the opinion of the writer. However, these same features have been denied such a significance many times by proponents of granitization and are offered here only as features that must be explained. The presence in the region of many alaskitic bodies that are restricted to crests and troughs of folds (17) and the general lack of alaskite on the limbs of the folds could be accounted for by either hypothesis; either the movement of granitizing agents or the intrusion of magma would be facilitated in such zones of low pressure developed during folding.

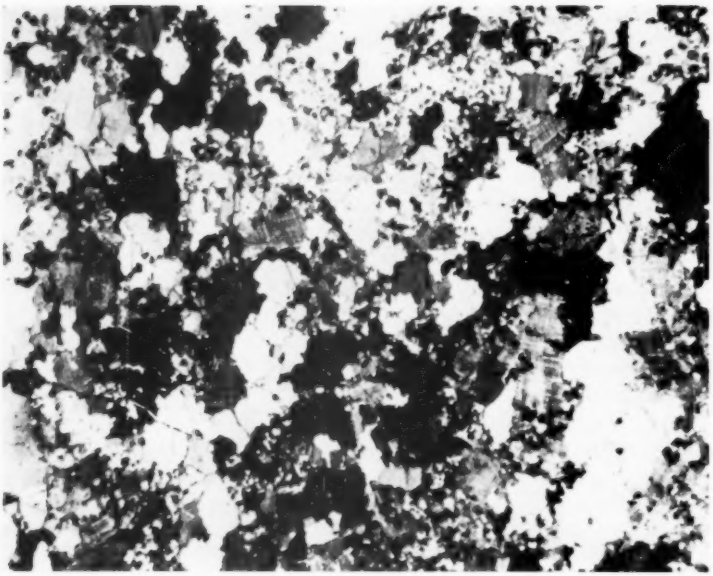
The balance of evidence, though much of it is admittedly only permissive, suggests that the alaskite body resulted from the consolidation of a magma rather than by the transformation of solid rock. Further, no known evidence is at odds with this interpretation.

CONTACT METAMORPHISM

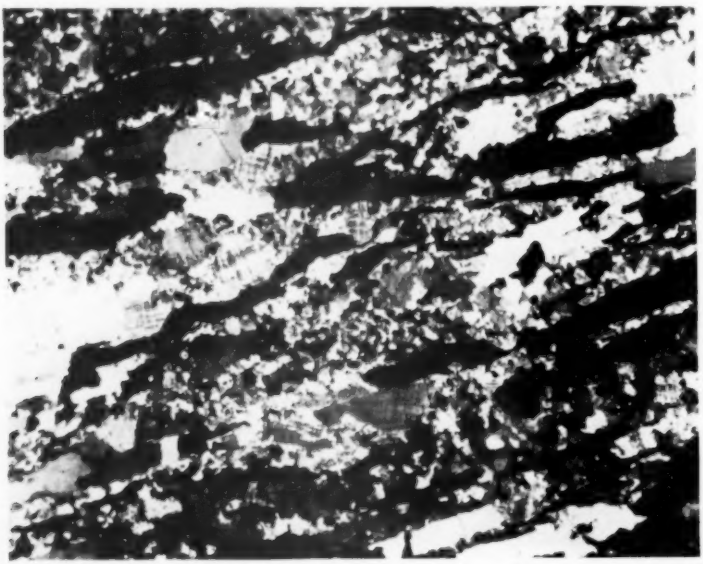
As mentioned above, metamorphic effects spatially associated with the Fish Creek mass were not given as criteria of magmatic origin for the mass because similar associations have been denied as having such a significance many times by proponents of granitization. However, since the mass has been shown to be of probable magmatic origin by using other criteria, a brief description of the metamorphic effects is in order. The following is a summary of the contact metamorphism as described and interpreted by the writer in another report, to be published.

Both exomorphic and endomorphic effects are present near the contact of the Fish Creek mass. The Grenville series rocks show evidences of reconstitution and introduction of material; the Fish Creek mass itself is notably

PLATE 4



A. Cataclastic perthite and quartz with some recrystallized quartz and minor amounts of albite (x 8).



B. Large cataclastic augen of perthite; granulated perthite; recrystallized quartz (x 8).

different in grain size and composition along parts of its contact.

There is no regularly zoned aureole around this mass. The exomorphism associated with the Fish Creek mass is similar to that associated with the granitic masses in the nearby Oxbow district as described by Agar (1923). Contact metamorphic minerals occur: 1) disseminated through large volumes of marble; 2) as irregular pockets both near the contact and at considerable distances from any visible intrusive contact; and 3) in completely altered bands that may represent former impure or dolomitic layers in the marble unit. Minerals found to occur within the contact zone are actinolite, albite, apatite, biotite, bowlingite (?), calcite, chondrodite, clinozoisite, cordierite (?), garnet (chiefly almandine), graphite, hornblende, leucoxene, microcline, microperthite, myrmekite, periclase (?), phlogopite, pyrrhotite, pyroxene (both augite and hedenbergite-diopside), quartz, scapolite (mizzonite-dipyre), serpentine, sillimanite, sphene, spinel (both green and colorless varieties), and tourmaline (both blue and brown varieties). The hedenbergite-diopside, scapolite, sphene, chondrodite, quartz, and different feldspars are the most common minerals other than calcite. Two especially common mineral associations are colorless spinel and chondrodite, and sphene, pyroxene (of the hedenbergite-diopside series), and scapolite. Locally, the spinel-bearing chondrodite marbles are now ophicalcites because of serpentinization of the chondrodite.

This contact metamorphism probably represents an addition of elements from the magma as well as recrystallization and rearrangement of elements to form the calcium and magnesium silicates. Among the elements probably added are boron, fluorine, chlorine, and phosphorus, represented respectively by the minerals tourmaline, chondrodite, scapolite, and apatite.

Other petrographic types associated with the Fish Creek mass that have been attributed to exomorphism associated with similar alaskite gneiss bodies in this province are garnet gneiss, "amphibolites," and quartz-oligoclase rocks (Buddington, 1939, p. 169-172).

Garnet gneiss was found to occur in four places in and near the Fish Creek body. It occurs as thin layers in the marble south of the mass and as xenoliths within the mass. The gneiss is composed essentially of almandine, sillimanite, microperthite, andesine, quartz, and biotite with minor amounts of green spinel, sphene, myrmekite, zircon, apatite, sericite, and opaque minerals. Locally, sillimanite is absent. The origin of similar garnet gneiss in this general region has been a subject of great interest since Martin's discussion (1916, p. 24-40) of different possible origins for it in the Canton quadrangle. He concluded that the garnet gneiss resulted from metamorphism of siliceous-aluminous sediments. Buddington (1929, p. 96-105) reviewed objective data concerning the gneiss and concluded that it originated as a consequence of interaction between a portion of granitic magma enriched in hyperfusibles and/or thermal solutions and an earlier-formed amphibolitic facies (which was formed by prior contact metasomatism of marble). The writer favors the idea that the garnet gneiss spatially associated with the Fish Creek mass was derived essentially by simple reconstitution of aluminous-siliceous sedimentites.

Many petrographic types are included in the term "amphibolite" as that term has been used by former workers in this general region. Included are various plagioclase foliates that contain biotite and/or hornblende and/or pyroxenes (clino- and/or ortho-). Gneissic hornblendic pyroxene-plagioclase rocks predominate in the Fish Creek mass. Most of the rocks of this type appear to have had essentially their present character before intrusion of the alaskite magma.

The quartz-oligoclase rock—trondhjemite—along part of the periphery of the alaskite body is believed to represent endomorphism rather than exomorphism. The rock is typically dark gray or greenish gray, medium grained.

PLATE 5

Large leaves of recrystallized quartz; albite and microcline (x 19).

and massive and is composed of zoned, antiperthitic plagioclase feldspar (An_{27-32}), 45 to 65 percent; strained quartz, 20 to 40 percent; and minor amounts of biotite, apatite, zircon, and ilmenite (with included magnetite lamallae) plus or minus hornblende, diopside-hedenbergite, myrmekitized microcline-microperthite, pyrite, and epidote. The trondhjemite grades imperceptibly into the alaskite of the main mass and it contains inclusions identical in composition to those in the main mass. Its chemistry and mineralogy suggest that it represents a portion of the alaskite magma that was contaminated by the calcareous country rock.

EMPLACEMENT

The source of the alaskite magma is not known. It could represent part of a primitive magma, a fraction of a differentiated magma, or a magma derived by partial or complete fusion of pre-existing rock. Data available in this area apparently do not preclude any of these possibilities. The widespread distribution in the region of alaskite like that in this mass (Buddington, 1939, pl. 23—the alaskite is equivalent to his "Alexandria Type" granite), the fact that it cuts all other major pre-Potsdam rock units in the region, its occurrences in many phacoliths and a major batholith, and its highly silicic composition are data that, in conjunction with the features already mentioned, must be considered.

The writer favors the possibility that the alaskite magma was derived by partial or complete remelting of pre-existing rock and that the phacoliths represent portions of the magma, so formed, that moved away from the main mass. Many features are in accord with any suggestion that would place the phacoliths in a critical zone where conditions favoring fusion and refusion obtained. It is considered not impossible that the alaskite represents an easily fusible portion of the basement upon which the Grenville Series rocks were deposited.

No matter what the source of the alaskite magma, all evidence suggests that the portion of it that solidified to form the Fish Creek mass came to occupy its position mainly by permissive intrusion. (Permissive intrusion was defined by Pirsson (1914, p. 299) as intrusion in which magma is emplaced by flowing into space that opened for it, the openings being formed mainly by some force other than one exerted by the invading magma.) In the case of the Fish Creek mass, the magma is believed to have flowed into potential cavities created by tectonic stress at the trough of a fold.

The general type of injection thought to have been mainly responsible for emplacement of the Fish Creek alaskite may be explained as follows: During folding, crests and troughs of folds become zones of relative weakness and general tension, whereas the flanks of folds become relatively compressed. If the materials being folded have competencies such that they will flow during the folding, folds will be produced that show thickening varying directly with the mobility of the material involved; if on the other hand, the materials involved have competencies such that they will fracture rather than flow under the conditions of the folding, there will be a tendency for openings to form along planes of weakness (e.g., foliation or bedding planes) at the crests and troughs of the folds. If igneous magma were present during such folding, it probably would find its way into the zones of weakness along the crests and troughs of the folds in the more rigid rocks. After the initial permissive introduction of the magma into the potential openings, there might be further enlargement of the interspaces and addition of more magma until the original rock would be dismembered completely and become discrete fragments (xenoliths or inclusions) within the magma. The enlargement of the interspaces between fragments of the country rock might be dependent upon continued folding, simultaneously with addition of more magma, or upon forces exerted by a somewhat aggressive magma. Whichever the case, if enough magma

were supplied, it would finally become the predominant member of the unit, and the unit would then act like a mobile material so long as any notable part of the magma retained its fluidity. Upon consolidation the resulting mass would be a concavo-convex, lenticular-shaped mass containing many sheetlike inclusions or splinters of the injected country rock.

Because this general mode of intrusion appears to explain all features

PLATE 6
Metagabbroid (?) dikes

A. Folded dike.

B. Faulted dike.

associated with the mass, and because no known features associated with the mass preclude this mode of emplacement, it is concluded that the Fish Creek alaskite was so emplaced. Further, no mode of emplacement, except syntectonic, permissive intrusion into the nose of a fold, has been found that is in complete accord with the thickening of the nose of the mass, the orientation and peculiar shapes of inclusions within the alaskite, and the fabric differences in the alaskite.

POST-EMPLACEMENT HISTORY

Subsequent to the emplacement of the phacolith the mass has been intruded by gabbroid (?) magma; intruded by basaltic magma; and uncovered by weathering and erosion at least two times.

A small basaltic dike cuts the mass near its southern margin just south of the marble embayment. The basalt is composed of labradorite, 45 to 60 percent; pyroxene (augite and pigeonite), 30 to 40 percent; olivine, up to 10 percent; and opaques, up to 8 percent. Its texture is diabasic, and although the rock is now holocrystalline, it appears as if it once had a mesostasis of glass. The chilled margins are composed of the same rock with modifications typically associated with rapid consolidation. The dike cuts the foliation of the alaskite, has chilled margins, and is unmetamorphosed.

The present exposure of the Fish Creek phacolith plus the fact that it is overlain locally by Potsdam sandstone shows that the mass has been exposed by weathering and erosion at least two times.

At least 18 gabbroid (?) dikes, ranging from a few inches to nearly two feet in width, cut the foliation of the Fish Creek alaskite gneiss and intersect some of the inclusions within the alaskite. The dikes are of special interest because this is the first mass in the northwest Adirondack province in which they have been recognized and because they may throw new light upon the conditions that prevailed during the late stages of alaskite magmatism. Petrographically, the dikes are now typical amphibolites and are composed of andesine, 45 to 55 percent; hornblende, 35 to 45 percent; magnetite, up to 8 percent; and minor amounts of apatite, titanium-rich biotite, and zircon. No relict igneous textures are apparent in thin section. In the field the thicker dikes may be seen to have fine-grained borders and the thinner ones are fine grained throughout, possibly representing relict chill zones. Subsequent to intrusion, these dikes have been dynamically deformed, reconstituted (?), and have been cut by pegmatitic material.

Two dikes of this type are of particular interest (pl. 6-A and B). Features associated with them suggest that they were intruded before at least the latest period of alaskite mobility: the folded dike, which occurs near the axial plane zone of the phacolith, has its axial plane nearly parallel to the axial plane foliation of the alaskite; the fabric of the alaskite in the area immediately adjacent to the fault that cuts the other dike (pl. 6-B) does not show cataclasis and does not have a fabric different from that of the rest of the alaskite of the same general zone. Foliation in the wider dikes is parallel to the margins of the dikes near the margins and is a compromise between that and that of the Fish Creek alaskite axial plane type in the central part of the dikes;

the dikes are injected locally by pegmatite of the same composition as that of the alaskite.

The origin of the magma that formed these dikes is questionable. Perhaps it represents xenolithic material (inclusions) that sank into a zone where it became at least partially melted and thus gained mobility; perhaps it represents spessartite material or some similar type of late differentiate of the alaskite. In any case the magma apparently came into fractures during the tectonism responsible for injection of the phacolith and during a period when the alaskite was at a critical level or in a critical state, i.e., the alaskite alternated between solid rock that could be fractured and magma or mush that could flow. This interpretation is not unlike that suggested by Sederholm. (1926, p. 22, 39-51) with regard to the inclusions in the granite at W. Bagaskär, Ingå, Finland. Inclusions in the granite there were interpreted to be dismembered mafic fillings of fissures; it was suggested that the fillings were formed by material that exuded from the granitic host and filled fissures in that host while the host was still in a critical state, i.e., it was in such a state of aggregation that fissures could form in it but a portion of it still retained its capacity to flow so it thus had mobility enough to permit the movements that dismembered and floated apart the mafic fissures fillings. Another interpretation that cannot be ruled out completely is that given by Sederholm (1926, p. 39-55) for inclusions in the granite near Pavåskär, Ingå, Finland. He suggested that mafic dikes were injected into a series of rocks that subsequently became mobile because of palingenesis in situ.

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SOIL TONGUES AND THEIR CONFUSION WITH CERTAIN INDICATORS OF PERIGLACIAL CLIMATE

LYNN A. YEHLE

ABSTRACT. Homogeneous soil-like materials in wedge-shaped, tapering bodies have been reported in unconsolidated deposits in temperate climates. By analogy with structures found in areas underlain by permanently frozen ground they are thought to bear evidence of periglacial climatic conditions.

Certain solution structures (soil tongues) may be confused with frost crack and fossil ice wedge fillings. Soil tongues originate through differential solution operative with soil formation upon calcareous, coarse-grained surficial deposits. Because soil tongues form in humid temperate climates where periglacial conditions may once have been active, their correct interpretation is important.

INTRODUCTION

Wedge-shaped structures extending downward into unconsolidated deposits have been reported by several investigators from surficial accumulations in temperate climates. These are thought to reflect the more rigorous climatic conditions of a periglacial environment (Cailleux, 1943; Denny, 1936; Fearnsides, 1940; Horberg, 1949, 1951; Paterson, 1940; Wolfe, 1953). By analogy with forms now found in areas underlain by permanently frozen ground these features have been ascribed to filling of "ice wedges" and "frost cracks." Their presence has been used to reconstruct the varying climatic conditions of the immediate geologic past.

This paper describes solution structures which may be confused with fossil ice wedge and frost crack fillings. Pedologists refer to them as "soil tongues." The fact that these may form in temperate climates where periglacial conditions might once have been active gives their correct interpretation added significance.

HISTORY OF INVESTIGATION

The structures which have prompted this report were first examined in the field during the summer of 1949 by Dr. Sheldon Judson and Mr. Joseph Roberts, both of the Department of Geology, University of Wisconsin. This preliminary investigation concluded that the features were frost-crack fillings developed under periglacial climatic conditions.

In May 1950 they were included as a stop in the first annual field conference of the midwestern "Friends of the Pleistocene."[1] The fact that these structures were initially interpreted as frost features gives added warning to the importance of their proper identification.

[1]The "Friends of the Pleistocene," an informal organization composed of those interested in various aspects of the Pleistocene, was founded in 1933 by Professors Richard Foster Flint, George White, and J. Walter Goldthwait. The first meeting was held in the New Hampshire coastal area. Since then (with the exception of the World War II years) an annual field meting has been held at various spots in the northeastern states. In 1950 Professor Sheldon Judson led in Wisconsin the first field meeting of a midwestern group of the "Friends." In 1952 a Rocky Mountain section of the "Friends" was organized at the Salt Lake City sectional meeting of the Geological Society of America. The first field meeting of this group was led by Mr. Gerald Richmond in Rocky Mountain National Park.

When the writer undertook a detailed study of these features in the fall of 1952, they were still thought to be relics from a past periglacial climate in south-central Wisconsin. Excavation during that fall and the fall of 1953, as well as a survey of the literature, correspondence with other workers, and examination of similar features in Ohio, demonstrates that they are not fossil ice wedges or frost-crack fillings but owe their genesis largely to differential solution.

NATURE OF SOIL TONGUES

General Statement

Solution by waters percolating downward from the surface through soluble earth materials may produce a variety of effects most of which are familiar to geologists. Of less familiarity to them are differential solution effects which are evident along the base of many soil profiles. These solutions and variations in parent material produce the irregularities visible in subsoil-parent material boundaries. Thus, vertical, lobe-like subsoil extensions appear to penetrate downward into the parent material. These extensions are referred to as soil tongues by pedologists (Brown and Thorp, 1942, p. 14-15), but reference to them in most of the soils literature is meager. Goldthwait (1952) uses the term soil pendant. Though soil tongue is not entirely satisfactory as a name for the solution structures discussed, the writer feels that acceptance of the term by soil scientists warrants its use in this paper.

Usually soil tongues are but a few inches in vertical dimension and mark the slightly irregular base of the B horizon as it develops downward into parent material. They are best developed in the B_2 subhorizon of the pedalfer soils forming in calcareous, sandy gravel deposits.

The soil tongues here described are large in size, reaching 5 to 6 feet in depth. Because they may be confused with structures of different genesis, their recognition by the geologist interested in surficial deposits is important.

Soil tongues were studied in detail in an exposure in south-central Wisconsin, and similar features have been examined in Ohio. Still other tongues have been reported to the writer by investigators working in Indiana.

South-central Wisconsin

General setting.—The soil tongues most thoroughly investigated in the course of this study were located in a gravel pit excavated in deposits of Cary age in the NE¼NW¼ sec. 13, T. 11 N., R. 8 E. (Dekorra Township), west-central Columbia County. It is 13 miles south of Portage, Wisconsin, on County Highway "V" and 2½ miles south of Dekorra (fig. 1).[2]

The gravel pit, formerly operated by the Poynette Cement Block and Products Company, is now owned by the Madison Brick Company, Route 3, Madison, Wisconsin.

The pit is a few hundred feet south and east of the confluence of the Wisconsin River and a small unnamed creek. The valley is now partially

[2]Since completion of this work, two additional soil tongue exposures have been found in a gravel pit and in a county highway road cut in the NW¼SW¼ sec. 34, T. 11 N., R. 8 E. (Columbia County, Wisconsin).

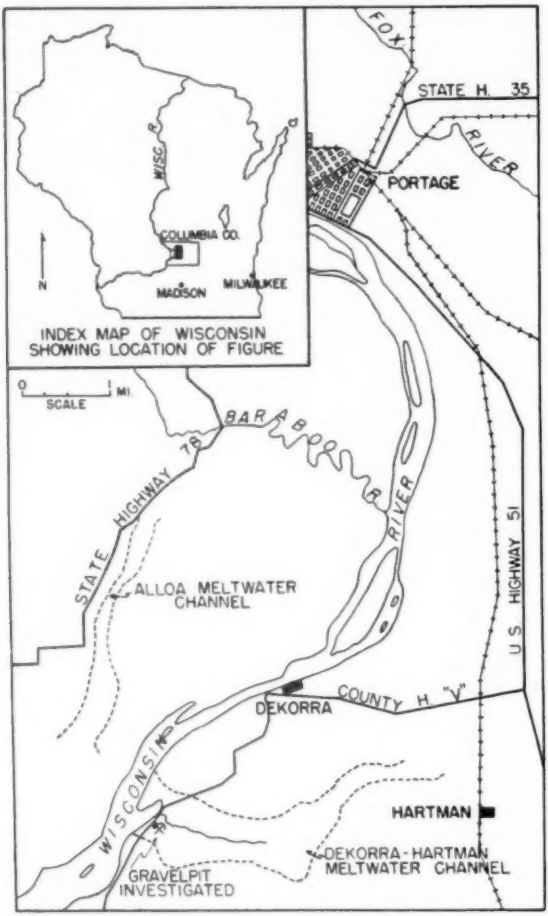

Fig. 1. West-central Columbia County, Wisconsin (after Thwaites, 1943, fig. 15).

drowned by waters impounded behind the Prairie du Sac Dam, 14 miles south on the Wisconsin River. Back water level is maintained at a mean elevation of 774 feet above sea level. Before damming, the river level was 22 feet below average pit elevation.

The glacial geology of the area is included in a *Map Showing the Surficial Deposits of Southeastern Wisconsin* (Alden, 1918, pl. 3), and briefly discussed by Bretz (1950). Thwaites (1943, fig. 15) partially remapped the area for his report on the glacial geology of northeastern Wisconsin. A modification of Thwaites' map is reproduced as figure 1.

A reconstruction of the Cary substage glacial history of the immediate area shows that a glacial meltwater channel between Hartman and Dekorra was active early during the excavation of a preglacial valley at the site of the

present Wisconsin River (fig. 1). Because of rapid downcutting by the Wisconsin River, this channel was short-lived. The outwash material brought down and deposited in it is exposed in the gravel pit discussed in this paper.

Since accumulation of the outwash, wind activity has been locally important. The finer material was picked up from younger beds and redeposited.

Pit description.—Four main elements were present in the gravel pit opening. They were: (1) a sandy gravel outwash high in limestone and dolomite; (2) a dune sand cover; (3) a silt loam "pan" between the dune sand and the outwash; (4) soil tongues extending downward into the outwash below the "pan" (fig. 2-A).

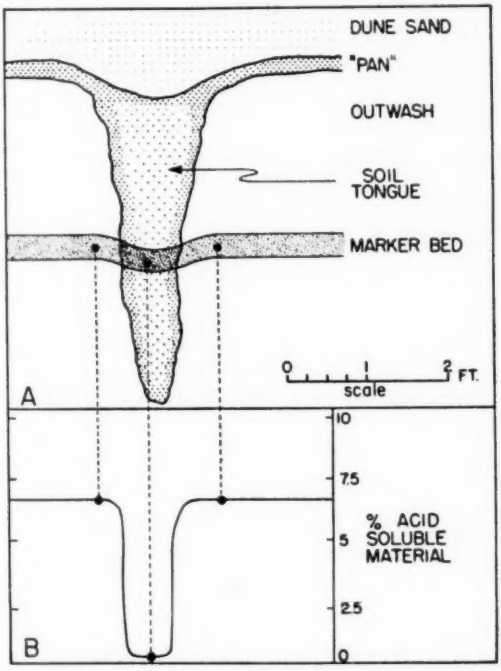

Fig. 2. A, Cross-section of soil tongue. B, Curve of percent loss of acid soluble material from unaltered outwash to soil tongue.

(1) *Outwash.* The discontinuous beds of sand and gravel outwash were exposed in the working face of the pit. In general, the outwash varied in grain size from pebbly sand and sand in the north near the small creek to a pebbly gravel and sandy gravel toward the southern limit of the exposure, over a distance of 60 feet. Although most of the outwash in the pit was composed of gravel with poorly defined bedding contacts, well-delineated white quartz sand layers occasionally occurred in the sequence. These well-bedded layers provided excellent marker beds, and their importance in the interpretation of soil tongue formation is referred to below. The quartz sand layers increased in number and thickness toward the creek.

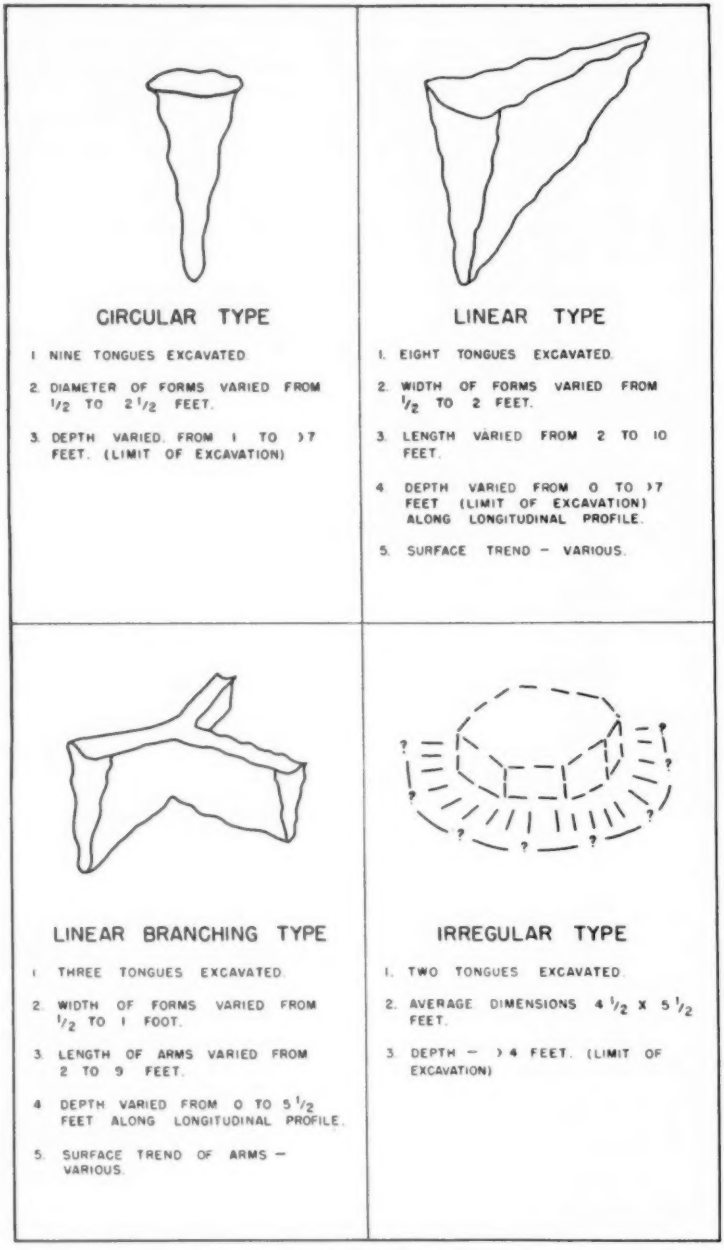
CIRCULAR TYPE
1. NINE TONGUES EXCAVATED.
2. DIAMETER OF FORMS VARIED FROM 1/2 TO 2 1/2 FEET.
3. DEPTH VARIED FROM 1 TO >7 FEET. (LIMIT OF EXCAVATION)
LINEAR TYPE
1. EIGHT TONGUES EXCAVATED.
2. WIDTH OF FORMS VARIED FROM 1/2 TO 2 FEET.
3. LENGTH VARIED FROM 2 TO 10 FEET.
4. DEPTH VARIED FROM 0 TO >7 FEET (LIMIT OF EXCAVATION) ALONG LONGITUDINAL PROFILE.
5. SURFACE TREND – VARIOUS.
LINEAR BRANCHING TYPE
1. THREE TONGUES EXCAVATED.
2. WIDTH OF FORMS VARIED FROM 1/2 TO 1 FOOT.
3. LENGTH OF ARMS VARIED FROM 2 TO 9 FEET.
4. DEPTH VARIED FROM 0 TO 5 1/2 FEET ALONG LONGITUDINAL PROFILE.
5. SURFACE TREND OF ARMS – VARIOUS.
IRREGULAR TYPE
1. TWO TONGUES EXCAVATED.
2. AVERAGE DIMENSIONS 4 1/2 X 5 1/2 FEET.
3. DEPTH – >4 FEET. (LIMIT OF EXCAVATION)

Fig. 3. Type, trend, and dimensions of tongue structures.

(2) *Dune sand.* This deposit irregularly overlies the pit area, ranging in thickness from 3 to 6 feet.

(3) *Silt loam "pan."* This horizon is sharply delineated from the underlying outwash and overlying dune sand by its reddish-brown color and difference in composition. Pebbles present in this "pan" consisted mainly of chert fragments and some highly decomposed limestone and dolomite pebbles in a silt loam matrix. The thickness of this horizon varied from 3 to 4 inches.

(4) *Soil tongues.* These striking soil bodies were identical in texture and composition to the "pan" between the dune sand and the outwash. The shape of these soil tongues varied from tapering pipe to wedge-shaped and are described in more detail below.

Detailed description of soil tongues.—A three dimensional examination of the gravel pit was undertaken to obtain a clear picture of the various shapes, sizes, and trends of soil tongue forms. Vertical cuts were made by shovel at ½- to 1-foot intervals back into the face of the pit. These progressive slices were photographed and their nature recorded as to character of material, as well as width, length, and depth of soil tongues. On this basis, three general shapes were delineated (fig. 3).

(1) Some of the soil tongues excavated had little horizontal continuity and were apparently *circular* in ground plan, resembling conical or tapering pipes. The average diameter was between 1 and 2 feet.

(2) Most of the large scale forms were found to be definitely *linear* in ground plan—wedge-shaped in three dimensions. The average surface exposed was about 2 by 8 feet (pl. 1-A). A modification of this wedge-shaped soil tongue was termed the branching form.

(3) An *irregular* type is illustrated in figure 3. The ground plan of the two tongues excavated was somewhat obscure, but average dimensions were about 4 by 6 feet. Both soil bodies were homogeneous, showing no clearly discernible marker beds passing through them and continuing into the enclosing outwash.

In cross-section a generalized soil tongue would consist of a tapering reddish-brown silt loam body extending downward into the outwash for at

TABLE 1

Comparison Pebble Counts of Selected Tongues and Adjacent Outwash (20-30 mm. size fraction)

Pebble type	% Totals	
	Outwash	Tongues
Carbonates (limestone and dolomite)	65.9	10.4
Chert	7.2	29.2
Quartzite	4.0	8.0
Sandstone, Shale	5.7	11.6
Felsite	2.8	3.6
Silicic coarse-grained crystalline	4.4	11.6
Basalt	3.6	3.2
Mafic coarse-grained crystalline	4.4	16.1
Others	2.0	5.9
Totals	100.0	99.6
84.2% carbonate loss in tongues		

TABLE 2

The Relative Amounts of Acid Soluble Material in Marker Beds Between Soil Tongues and Adjacent Outwash (0.125-1.0 mm. size fraction)

	No. samples	% Acid-soluble	Range	% Soluble material lost
In outwash	6	6.8	4.7-7.9	
In soil tongues	6	0.3	0.1-0.4	95.7

least 4 feet (fig. 2-A and pl. 1-B). Pebbles in the silt loam mass included chert fragments, highly disintegrated limestone and dolomite pebbles, silicic and mafic crystalline pebbles, and shale and sandstone fragments. Table 1 compares the pebble composition of five averaged soil tongues and the outwash adjacent to each. Using the outwash composition as a base, comparison shows a marked decrease of limestone and dolomite pebbles in the tongues.

The margins of the soil tongues excavated usually tapered down to the blunt base of the structure, but in some forms the lowermost margins flared out considerably, making it appear to have a bulbous base. Occasionally the zone of contact between outwash gravel and soil tongues showed distinct marginal accumulation of iron oxide. The coloration was a deeper reddish-brown hue than that of the inner portion of the soil tongue. Toward the upper end of the tongues, the margins veered gradually from the vertical, flaring out and merging into the "pan" horizon. (Removal of dune sand in the exploitation of the gravel pit often destroyed this upper flaring end.)

Of great interest in a number of the tongues was the fact that beds of quartz sand in the outwash on either side of the structures continued unbroken through the tongues (pl. 2). Although horizontal continuity was maintained, the beds were bowed downward within the soil tongue. The fact that the marker beds were unbroken from the outwash through some tongues demonstrates that the tongues were formed by alteration of outwash material in situ and not by filling of a crevasse from above. Samples from selected marker beds were treated by acid leaching methods outlined by Richards et al., (1947, p. 93, method 8b). These demonstrated a distinct difference (in terms of acid-soluble material) between samples taken within the soil tongue portion of the individual beds and their continuation into the unaltered outwash (fig. 2). Treatment of samples from the outwash beds showed that they were composed of 4.7-7.9 percent material soluble in 0.5N hydrochloric acid. The same beds in the soil tongues contained only 0.1-0.4 percent of acid soluble material, showing a loss of 94.1-97.8 percent of the carbonate material from outwash to soil tongue (table 2). These observations point to the fact that solution has been very active in formation of soil tongues.

This conclusion is also substantiated by the pebble counts. Limestone and dolomite pebbles composed 65.9 percent of the outwash but only 10.4 percent of the average tongue sample. Thus, 84.2 percent of the carbonate material was lost between the two, with a relative gain in the other pebble types. Anomalous increases in some categories (notably silicic and mafic crystallines) result from the breakup of large pebbles. Because of this, fragments from the same pebble may have been counted more than once.

PLATE 1

A. Ground plan view of linear soil tongue. The tongue is 1½ feet wide and 8 feet long with a shovel standing on its surface. It is outlined by the shallow excavated trench (gravel pit south of Dekorra, Wisconsin).

B. Cross-section view of an homogeneous soil tongue. Note the absence of marker beds in the enclosing outwash (gravel pit south of Dekorra, Wisconsin).

Additional evidence of the importance of solution is reflected in the reduction of grain size in the tongue material. The cumulative grain size curves shown on figure 4 indicate the magnitude of this reduction by comparing the mechanical analyses of gravel beds in the outwash, where fresh, and in the tongues, where partially decomposed. The median diameter of outwash samples was 0.51 mm. and of soil tongue material, 0.38 mm. Computation of the coefficients of sorting showed a value of 1.92 for the selected

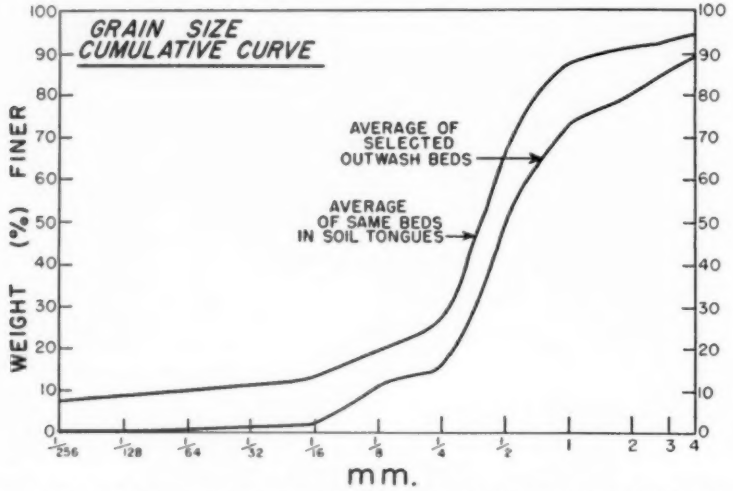

Fig. 4. Grain-size cumulative curves of selected outwash beds and same beds in the soil tongues (0.0039-4.0 mm. size fraction).

outwash beds and 1.67 for the same beds in the soil tongues. Standard mechanical analysis techniques were employed following Twenhofel and Tyler (1941) and Krumbein (1932, 1935).

Ohio and Indiana

Occurrence of soil tongues reported from Indiana and observed by the writer in Ohio is the result of normal soil profile development upon calcareous glacial and fluvial gravel. They are typically a part of the Fox Series of soils. Brown and Thorp (1942, p. 14-15) describe the Fox silt loam B_3 subhorizon as a

> " . . . dark-brown, gritty and sticky silty clay with a slightly reddish tint and an indistinct blocky structure. Contains many pebbles, more or less disintegrated and, although the reaction is approximately neutral, no limestone fragments remain. This rests abruptly on stratified gravels beneath. The lower boundary of the horizon is very irregular in shape and narrow tongues extend to 4 or 5 feet deep in many places."

Large areas of the Fox Series of soils are found in central Ohio and in Indiana.

In June, 1953 the writer examined several stops visited by the 1952 field conference of the eastern "Friends of the Pleistocene" to compare the soil tongues of central Ohio with those described above in Wisconsin. (Field guide stops #2, 3, 5, and 10; Goldthwait, 1952).

Discounting the lack of a complete soil profile associated with the tongues in the south-central Wisconsin exposure, the Ohio tongues are physically similar: (1) in general cross-section; (2) in exhibiting downbowing of marker beds (if present); and (3) in lack of any obvious break in the continuity of the enclosing bedded material. Difference in the two occurrences should be pointed out: in the Wisconsin exposure, (1) absence of complete soil profile, (2) average depth of development of tongues was greater, and (3) marked areal continuity of many forms. Soil tongues excavated by the writer in Ohio "invariably peter out in any horizontal direction, they being extensive in depth only."[3]

In Indiana, soil tongues have been found and reported by Professor James Thorp of Earlham College and Professor Thomas Bushnell of Purdue University. They describe B_3 subhorizon extensions similar to those in Ohio[4] —a jumbled mass of reddish-brown silt to clay loam, partially decomposed carbonates, and residual pebbles that tapers downward into unweathered glacial and fluvial calcareous deposits. With adequate marker beds, subsidence is shown by downbowing of the bedding. Thus, where marker beds are absent, one cannot assume any vertical break in the indistinctly bedded unconsolidated material enclosing the structures.

Conclusions

1. Soil tongues may reach large size, extending down to depths in excess of 7 feet, and assume at least three general areal patterns: linear, circular, and irregular.

2. In those tongues in which marker beds continue through the tongues, no deep vertical break in the original deposit can be invoked to explain the gross form of these structures. It is then logical to presume that in associated soil tongues with no such markers there has been no original surface break involving the parent material.

3. The loss of carbonate material between soil tongues and outwash strongly suggests solution as the major agency of soil tongue formation through alteration of parent material in situ. They do not represent filling of a crevasse with material from above.

4. Pedologists consider most soil tongues to be extensions of the normal irregularities marking B_3 subhorizons. In addition, they note that best development is found in the Fox Series of soils where amplification of these irregularities is probably taking place in present-day humid temperate regions.

ORIGIN OF STRUCTURES

Clearly, frost action could not have produced these conical and wedge-shaped soil tongues. Percolating water bearing organic acids and carbon dioxide is capable of solution and deposition on a scale adequate to explain the vertical and lateral enlargement of these forms.

This process in the Fox Series of soils takes place in calcareous glacial or fluvial gravel parent material where the topography is level to gently rolling and annual precipitation amounts to 25 inches or more. As water percolates

[3]Professor Richard Goldthwait, personal communication, dated February, 1953.

[4]Personal communications, dated January and November, 1953, respectively.

PLATE 2

B

A

Cross-section views of soil tongues. Note the persistence of marker beds through the soil tongues and subsidence of marker beds in the tongues. The length of the shovel is 20 inches (gravel pit south of Dekorra, Wisconsin).

into the parent material, the solution and accumulation processes gradually move deeper as a highly irregular weathering front at the contact between the base of the B horizon and the underlying unleached calcareous gravel. The irregularities in this front are maintained and amplified through differential solution because of a natural channeling of percolating water into them. They are in essence "lows" on the active weathering front.

The areal distribution of these irregularities is thought to depend upon the initial ground surface configuration or upon later conditions that altered it. Proposals that have been considered are, (1) very shallow ice wedges or frost cracks; (2) shallow desiccation cracks; (3) tree roots and fallen logs; (4) faulting; and (5) micro-relief of the original ground surface.

(1) Considering shallow ice wedges or frost cracks as altering the surface of the deposit, one must realize that even if cracks are very shallowly developed no discontinuity is present in the outwash bedding stratigraphically below the break. Black (1952, p. 130) points out that Arctic ice wedges begin as minute cracks where the active permafrost layer is split. These are probably the tension cracks of Taber (1943, p. 1521). Permafrost investigation shows the infrequence of ice and frost-cracking in well-drained, coarse-textured materials. The depth of most reported ice wedges is too great to explain the shallow surface alteration allowing differential solution to take place in the situation described.

Frost cracks, which are developed to lesser depths, might entirely be concealed in homogeneous soil tongues and thus account for initiation of solution along vertical zones. This explanation, though, does not explain the conical-shaped structures.

(2) Shallow desiccation cracks might possibly have caused vertical zones of weakness in the ground surface during an arid interval before soil formation started. The coarse texture of these crack fillings and lack of explanation of conical-shaped structures casts doubt on the validity of this proposal.

(3) Tree roots and fallen logs must be discounted because of the complete lack of carbonized material, root fillings, and discontinuity in the bedding.

(4) Faulting could conceivably cause zones more susceptible to solution. If shallow, they could be completely concealed in homogeneous soil tongues where marker beds were absent. At the Wisconsin locality some normal slump faulting within stratigraphic marker beds was examined with respect to a linear soil tongue. The two were found to intersect at an acute angle and were in no way related. Thus, where faulting has been observed, there is no demonstrable genetic relation to the soil tongue. If faults did play a role in tongue formation, the evidence has either been destroyed or was not observed by the writer.

(5) Probably the most plausible explanation for the start of differential leaching in specific zones is the channeling of rain water by initial surface irregularities (micro-relief) into circular, irregular, or linear-shaped depressions.

Thus, the depth to which tongue forms extend depended upon induced irregularities in the active weathering front and the long term climatic environment. The possibility that deep forms are evidence of interglacial soil formation outside the succeeding glacial margin and are continuing to deepen today is being investigated by Goldthwait and Thorp.[5]

GENERAL CONSIDERATIONS

Wedge-shaped structures in unconsolidated deposits have been reported by several investigators in surficial deposits in temperate climates. They conclude that these structures are relics of a past periglacial climatic environment (Cailleux, 1943; Denny, 1936; Fearnsides, 1940; Horberg, 1949, 1951; Paterson, 1940; Wolfe, 1953). Description of some of these structures bears conflicting evidence as to processes involved and climatic conditions surrounding their formation. Zeuner (1945, p. 12) cautions that in general "Features suggestive of these phenomena, however, require a very careful scrutiny before they are interpreted climatically, since there are many structures which resemble them but are not caused by the effects of frost."

Specific warnings as to misinterpretation of shrinkage or desiccation crack fillings with physically similar frost crack and fossil ice wedge fillings have been offered by Hörner (1950, p. 237), Smith (1949, p. 1498-1499), Black (1952, p. 124, 132, and fig. 2), and Troll (1944, p. 549).

The study reported in this paper shows that additional forms, namely soil tongues formed by differential solution of unconsolidated, calcareous deposits, bear a striking resemblance to fossil ice wedge and frost crack fillings. The fact that these form in temperate climates where periglacial conditions may have been active adds a further warning to the problem of their correct interpretation.

A superficial study of these wedge-shaped structures may easily overlook (1) the nature and composition of the material contained, (2) the relationship of enclosing beds to the forms, and (3) the lack of any vertical break in the bedding. Among those that do cause a vertical break in the earth materials involved are ice wedges and frost cracks, and desiccation cracks.

Ice wedges and frost cracks.—The criteria for differentiation of these forms, and the circumstances surrounding their formation are not completely understood (Black, 1952, p. 131 and figs. 3 and 6). Regardless of this, it should be pointed out that soil tongues and fillings of frost cracks and fossil ice wedges may be easily confused because of ground plan and cross-sectional similarities. This raises the question as to whether or not some of the features reported in the literature as ancient frost cracks and fossil ice wedge fillings may not actually be solution structures. Unfortunately, the data included in many of the descriptions is insufficient to decide this point one way or the other. Misidentification would be easy: (1) where no associated frost action features were apparent; (2) where found in medium to coarse-grained carbonate gravel; and (3) where marker beds in the enclosing unconsolidated material were lacking.

[5]Personal communications, dated February and January, 1953, respectively.

Desiccation cracks.—In cross-section, the rock debris filling some desiccation cracks could be confused with the linear type of soil tongues or fossil frost forms if the conditions of formation were not completely understood.

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ON THE ORIENTATION OF LAKE BASINS*

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ABSTRACT. A theoretical horizontal circulation system is described for a circular lake with a constant wind blowing across it.

The shape of many oriented lakes in northern Alaska indicates that their present circulation system approaches the theoretical one, and that it is this system to which they owe their orientation.

Because the Carolina Bays are oriented along the probable direction of the winds which excavated them they are believed to be deflation basins, and not lakes whose shape is due to wave action and water circulation.

INTRODUCTION

The oriented lakes of northern Alaska have been described in some detail by Black and Barksdale (1949). Briefly, these lakes occur in an area of some 25,000 square miles adjacent to the Arctic Ocean. They tend to be elliptical or sub-elliptical in shape, and they have the very curious property of an almost identical alignment of their long axes, which are oriented slightly to the west of north.

The coastal plain upon which the lakes lie is a region of perennially frozen ground, and it has been suggested that many of them owe their origin to local thawing and subsequent collapse of the ground. Others, from their spatial relations to each other and to raised strand lines, are believed to have originated by the dissection of raised lagoons.

The cause of the curious orientation shown by most of the lakes of the Arctic Coastal Plain has remained a problem until the present time. Black and Barksdale drew attention to the close similarity between many of the Alaskan lake basins and the Carolina Bays. They believed that the conditions under which the oriented basins of both Alaska and the Carolinas had been excavated were similar, and they felt that the directive influence was probably that of the prevailing wind. In their own words, "Prevailing winds in the direction of the long axis of the Alaskan lakes are believed to be the chief factor that controlled their orientation."

This hypothesis offered two difficulties. In the Carolinas the present wind is extremely variable in direction, and in Alaska the prevailing winds, especially the ones above 15 miles per hour in speed, blow almost across the oriented lakes, not along them.

Odum (1952) has recently removed the first of these difficulties. Making certain assumptions about Pleistocene weather systems, he has reconstructed a weather map for the Carolinas during a maximum advance of the continental ice sheet and has shown that the resulting winds would tend to blow along the long axis of the Carolina Bays.

It is the purpose of this paper to remove the second difficulty by showing that the present wind direction in northern Alaska is actually sufficient cause for the existing orientation of the Alaskan lakes.

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OBSERVATIONS AND DEDUCTIONS

This paper grew out of observations made during the summers of 1951 and 1952, while investigating the paleo-limnology of northern Alaska. During field work in the regions of Point Barrow, Umiat and East Oumalik, and airplane flights over other parts of the coastal plain, the accuracy of the observations which had been made by Black and Barksdale (1949) was abundantly confirmed. Examination of aerial photographs provided by the Office of Naval Intelligence and of the Alaska Reconnaissance series map sheets of the U. S. Geological Survey provided additional corroborative data.

Only one point of disagreement arose with the observations of the earlier workers. It concerned their belief that in lakes of width permitting a sufficient fetch the orientation was becoming more easterly in response to present wind conditions. Actually, although occasional lakes can be found which are assuming almost any possible shape and orientation, they tend to be small ones, generally residual lakes in the center of a partially drained basin. There was no detectable general trend toward a change in orientation, and day-to-day observations upon the response of the lake shore to wind, which were made necessary by the fundamentally limnological nature of the main investigation, led gradually to the belief that the lakes were still in very close balance with the forces which had originally caused their orientation.

Thaw lakes are very mobile. Their shorelines change rapidly under the influence of summer storms, changes of several meters during a single storm occasionally being observed. Quantitative data for rates of shoreline retreat and advance over extended periods are very rare, but some data are available for East Oumalik Lake (69°, 50″ N., 155°, 27″ W.).

This lake is retreating along part of its shoreline, leaving a gently sloping plain behind it as it goes. Among the plants colonizing this plain are shrub willows of several species. The age of the oldest willows growing at a spot on the plain gives a measure of the length of time since the lake receded from that spot. From the systematic data shown in figure 1 it can be seen that the rate of retreat has been well over a meter a year for the last 70 years.

It would be unsafe to apply this rate too widely, for rates of shoreline advance and retreat are extremely variable. No single thaw lake is typical of all the thousands upon the Arctic Coastal Plain, but observations on a large number of lakes during the summer storms of two seasons indicate that one meter a year is at least of the correct order of magnitude.

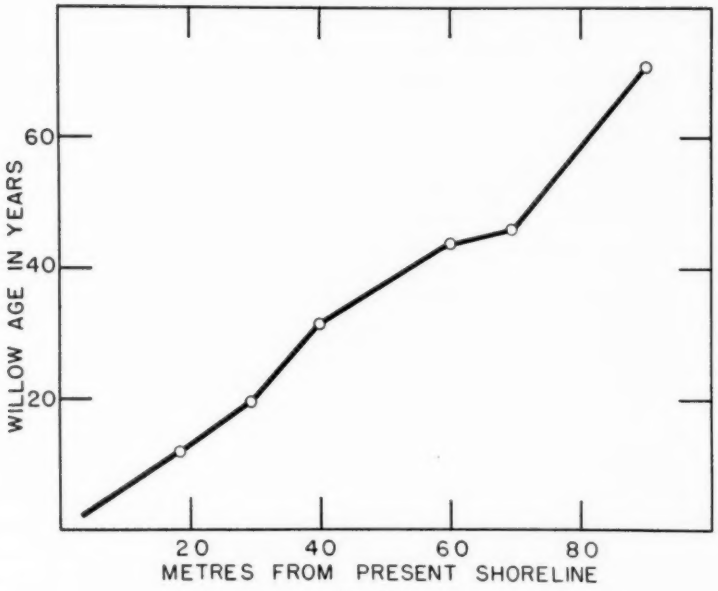

Fig. 1

At such a rate it would not take more than a few centuries for the oriented lakes to change their direction completely in response to a change in prevailing wind direction. The change to present wind direction which was postulated by Black and Barksdale (1949) must, then, have occurred during the last few centuries. It seems unlikely, from what is known of recent weather changes, that the direction of the northern Alaska winds could have changed by almost 90° in so short a space of time. In all likelihood the agency which imparted a common direction to the oriented lakes is still operative.

There are many possible sources of direction which are almost certainly negligible. The relief of the terrain is too slight for differential insolation to be important. The regional slope is too slight and too inconstant for the lakes to be stretched-out cryopedologic structures, even if structures of such a size were known. According to the best available evidence (Capps, 1931) the coastal plain is unglaciated, so the lakes cannot lie in or between glacially produced streamline forms. The mantle consists of a great depth of unconsolidated material (Payne, and others, 1951) which prevents bedrock topography from explaining the orientation of the lakes, and there is no geophysical evidence of a meteor shower (Black and Barksdale, 1949, p. 117). Of all the possible agencies only the prevailing wind seems at all likely.

It has always been assumed by people considering the problem that a lake being excavated or enlarged by the wind will grow fastest downwind. Blow-outs, at least in Alaska, actually do grow in this way, and it has been easy to reason by analogy that lakes should do the same. There is, besides, a certain intuitive probability to the idea that the shore which is under attack by the strongest waves is the one which will retreat fastest. There are, how-

ever, factors other than simple wave action which control the rate of shoreline retreat. Not only are currents necessary to carry away the material loosened by the waves but they are invariably produced whenever a wind blows over the water. In particular, a surface drift is produced which travels approximately in the direction of the wind, at least in shallow lakes.

It was formerly believed that the water brought to a shore by this surface current was returned by another which flowed along the bottom, the so-called undertow. Recent studies by Shepard (1948) on sea beaches have shown that this undertow is negligible, and that the return of water is by way of surface currents, called rip currents, which are nourished by longshore currents, and which flow out at right angles to the shore.

On sea shores it is sometimes difficult to understand the factors which govern the location of the return rip currents but for a small lake it can be shown that they are always at the ends.

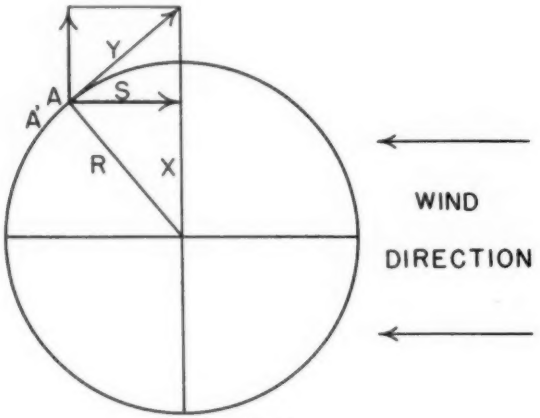

Fig. 2

Consider a small lake such as that shown in figure 2, shallow, filled with an ideal liquid, and over which a wind of uniform velocity is blowing. The wind will exert a force upon the surface of the lake which will cause a surface drift to flow across it. The rate at which water will be transported by this drift to any point A on the downwind side of the lake will depend upon the average velocity of the water arriving at A. This in turn will depend upon the width of the lake and also upon the acceleration. The actual relations are:

$$2s = u_a t$$
$$= \frac{at^2}{2} \quad (\text{because } u_a = \frac{at}{2}$$

$$t = \sqrt{\frac{4s}{a}}$$

Substituting this value of t in $u_a = \frac{at}{2}$

$$u_a = \frac{a\sqrt{\frac{4s}{a}}}{2}$$

$$= \sqrt{as}$$

where u_a is the average velocity, a is the acceleration due to the wind force, t is the time a water particle takes to cross the lake, and s is half the distance across the lake in the direction of the wind at point A. The amount of water arriving per unit time at any point on the downward shore will be:

$$t'\sqrt{as}$$

where t' is a dimension constant with a numerical value of one in the cgs system.

Since the amount of water arriving at a given point upon the downwind shore depends upon s in this way, the water will pile up to create a hydrostatic pressure difference between any two adjacent points, A, A', on the downwind side. The pressure gradient so set up will tend to accelerate the water over the interval AA' at a rate which will depend upon the steepness of the gradient and g, the acceleration due to gravity. That is,

$$\text{acceleration} = g \frac{d(t'\sqrt{as})}{dx}$$

where x is the distance of A from the center of the lake in a direction normal to the wind. Differentiating, we obtain

$$\frac{t'\sqrt{a}}{2\sqrt{s}} \frac{ds}{dx}$$

$$= \frac{t'x\sqrt{a}}{2s \cdot s}, \quad \text{because } \frac{ds}{dx} = \frac{x}{s}, \text{ the slope of the tangent at } A.$$

The acceleration producing a longshore current from A' to A will be greater near the ends of the lake than on the downwind side. As the current sweeps around the end of the lake, however, it will be flowing more and more against the wind force, which will tend to reduce it. This retardation depends upon the ratio between the component of the longshore velocity which is directly opposed to the wind force and the total longshore velocity, i.e., $\frac{s}{y}$ or $\frac{x}{r}$ in figure 2, and also upon the accelerating effect of the wind force in the following way:

$$\text{negative acceleration} = \frac{ax}{r}$$

The net acceleration, N, of the longshore current will be the difference between the accelerating and the retarding forces,

$$N = \frac{gt'x\sqrt{a}}{2s\sqrt{s}} - \frac{ax}{r}$$

$$= \frac{gt'\sqrt{r^2-s^2}\sqrt{a}}{2s\sqrt{s}} - \frac{a\sqrt{r^2-s^2}}{r}$$

It is possible for s to vary between zero and r. If we let it equal r as it does on the extreme downwind side of the lake, N becomes zero. If we let it equal zero, as it does at the ends of the lake, N becomes infinite.

Such an extreme value can never be obtained in nature, because of departures from geometrical circularity of the lake shape and the finite size of the moving parcels of water, but it is plain from the foregoing treatment that the acceleration, and hence the velocity, of the longshore currents is greater at the ends than elsewhere.

This theory of circulation is a first approximation only. It neglects several important considerations, notably eddy viscosity, depth of water, and variations of wind force over the surface of the lake. Of these factors, it seems likely that the first would decrease acceleration of the end rip currents, and the last two would increase it. Detailed analysis of these factors, and others, such as bottom roughness and Corioli's force, is beyond the scope of this paper, but it seems unlikely that anything beyond a quantitative change would be produced by them in a reasonably shallow lake. In lakes of over a few meters in depth it is probable that low-level return currents would have to be considered. Since the oriented lakes are very seldom more than 10 meters deep, and most are much shallower, it is very likely that they will obey the predictions of this theory rather closely.

The load which a current is competent to carry is dependent upon a power of its velocity, as is well known from studies of stream regimen, so the ends of the circular lake will tend to be scoured out by the longshore currents at a greater rate than the downwind shore, and the circular lake will gradually become elliptical or sub-elliptical, with its long axis at right angles to the prevailing wind.

Lakes whose bottom contours are visible from the air often show very good evidence of this scouring. Figure 3 shows sketch maps of lakes in the region around Teshekpuk Lake. It will be seen that there is, upon the downwind side of all these lakes, a very smooth, even, wave-action bench, which diminishes in width toward the ends of the lakes. In all lakes the bench is very narrow around the ends and in several there can be seen the marks of successive scours, which are no doubt the result of winds of different velocities. On the upwind side of the lakes there is another bench, even broader than the one on the downwind side. It is not so regular, however, and is cuspate in detail, just as one would expect of a bench which had been formed by deposition in a series of eddies.

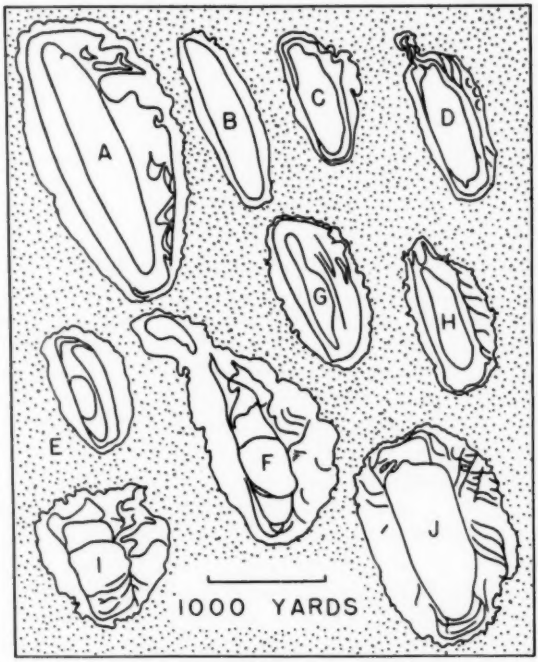

Fig. 3

These considerations provide an explanation for the orientation of the lakes and for the prevailing elliptical or sub-elliptical shape. It is not surprising that the lakes are seldom longer than the one shown in figure 3, B, for the wind of the Arctic Coastal Plain blows from a variety of directions other than the commonest northeasterly one. Other factors such as the finite size of moving water masses and the finite age of the lakes would limit the length of the basins even if the wind actually were constant in direction. It does not seem justifiable to state that the longest lake basins are the oldest, although they no doubt have a tendency, all other things being equal, to be older than the lakes of more nearly equiaxial elliptical shape.

It is difficult to see how the dynamics of erosion can be responsible for the sub-rectangular lakes which are found in some areas, but other explanations are usually available for these relatively scarce deviants from the usual shape. Black and Barksdale (1949) have shown that many of these lakes lie in rows behind raised strand lines, and in these the confining influence of the fossil beach bars may have squared off the basins. In other areas it is probable that longitudinal dunes act in the same way.

Other variations in the shape of oriented lakes are usually due to the complicated histories of individual basins. Coalition of neighboring basins, draining or partial draining and the influence of local topography all tend to vary shape, but it is not this variation which has been puzzling about the lakes of northern Alaska. The problem has been their general similarity, and this is fully understandable in the light of the postulated circulation system.

Since Alaskan lakes not only lie across the prevailing wind but were formed across it, some reconsideration must be given to the suggestion of Odum (1952) that the Carolina Bays were formed by a wind blowing parallel to their long axes. The Bays cannot have been excavated by such a wind while they were full of water, for then they would lie at right angles to their observed direction. If they were actually excavated by a wind from the direction his calculations suggest, then they must have been excavated as deflation basins during a period drier than the present. This is in full accord with his deduction (p. 269) that the relative humidity while the wind blew was low, and the precipitation less than it is today.

If the deductive approach used in this paper is valid, then the oriented lakes of Alaska are being excavated wet by winds which blow across them, and the Carolina Bays were excavated dry by a wind which blew along them.

Though these are the most spectacular fields of oriented lakes which are known, other fields occur elsewhere in the world. The largest, in northern Siberia, is probably of the same type as that in northern Alaska. The local fields which occur throughout the arid and semi-arid regions of the world, on the other hand, are almost certainly deflation basins. The large pans of the Lake Chrissie region, South Africa (Wellington, 1943), probably represent a special case, dominated by bedrock relief and an abandoned drainage channel.

It is very likely, though by no means certain, that orientation of lakes by end-current erosion is restricted to regions of perennially frozen ground. The fine-grained silts and sands of polar coastal plains, with their large included ice wedges, are peculiarly liable to attack by the combined action of waves and currents.

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QUANTITATIVE DIFFERENTIAL THERMAL ANALYSIS OF SOIL CLAYS AND SILTS

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ABSTRACT. The results of a series of thermal analyses for some clays and silts from soils in varying stages of maturity and derived from an arkosic parent material are quantitatively evaluated, and are correlated with X-ray and chemical analyses. The system investigated comprises kaolinite: quartz: the thermal peaks differ in area with grain-size variation and method of specimen packing.

INTRODUCTION

The theory of differential thermal analysis is based upon the fact that if two samples, one of which undergoes a phase change at a certain temperature, are heated in separate sample holders, the material undergoing the phase change will either absorb or emit heat from or to its surroundings, and thus there will result a difference in temperature between the two materials. Should such a phase change be reversible, then upon cooling the reverse change will be observed to take place. For any one compound a phase change will take place over a temperature range peculiar to that material, and here, therefore, is the means by which qualitative estimation may be effected. The quantitative aspect may be evaluated by measuring the amount of heat involved in the change of a known weight of the material in question, and relating this to standard curves. This heat change associated with phase change is measured by a differential thermocouple, and thus for any reaction a curve may be plotted.

The literature on qualitative estimations is copious, but quantitative measurements are rarer. Le Chatelier (1887)—the originator of the method—suggested that quantitative estimations were possible, but the first apparent application was that of Matějka (1922) working with clays. Among those who have used the method as a quantitative tool in the study of clays are Hendricks and Alexander (1939), Hendricks, Nelson, and Alexander (1940), Norton (1939), Grim and Rowland (1942), Schafer and Russell (1942), Jeffries (1944), Speil et al. (1945), Dean (1947), Grimshaw, Heaton, and Roberts (1945), Kerr and Kulp (1948). These and other workers have pointed out the danger of correlation of unknown specimens with graphs drawn from synthetic mixtures.

In the materials investigated in this work the clays and silts were used as their own standards and hence their physical characteristics remain the same. The apparatus used is rather similar to those described by Norton (1940) and Berkelhamer (1945). Photographic recording of reflecting galvanometers is employed. The sample block is of nickel and permits three samples to be investigated at one time. Thermocouples are of no. 26 S.W.G. chromel-alumel wire with junctions encased in nickel foil of known weight, and by this means the size of the thermocouple bead can be controlled. The standard used in this work was calcined analar. alumina of weighed amount (0.3000 gm). Temperature rise was linear at 10° C. per miunte up to 400° C., and then gradually increased to 12° C. per minute at 1000° C. Because of the use of nickel foil about the thermocouples, the tables compiled by Roeser, Dahl and Gowens (1935) may not be used, and therefore standardization

of the instrument for temperature was absolute, and effected by using thermometrically fixed points: boiling water—100° C., quartz—573° (α - β inversion), barium carbonate—811° and 982° (α - β - γ inversions), strontium carbonate—926° (α - β inversion), lead sulphate—865° (α - β inversion). These values were taken from Kracek (1942). Thus at each of the inversions the offset of the temperature thermocouple from zero could be measured. An almost straight line graph resulted, and this is shown in figure 1. The

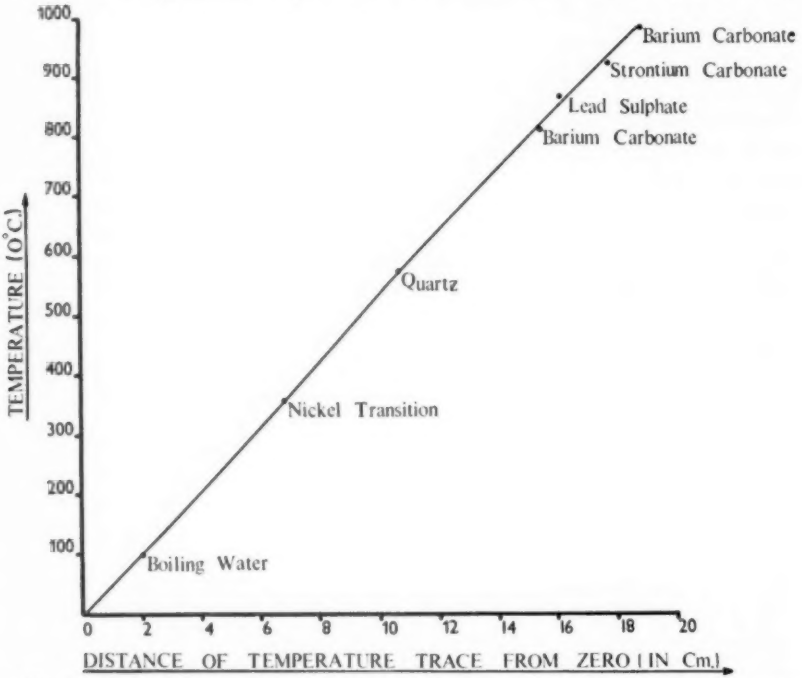

Fig. 1. Temperature of furnace as deduced from displacement of temperature trace from zero.

use of nickel sheathing provided an additional temperature check, for at the magnetic transition of nickel, which Möser (1936) gives at 354° ± 1° C., there is a slight heat effect and the differential thermocouples show a slight indentation in their graph, while the slope of the temperature trace changes abruptly. Thus every record contains in itself a check on the efficiency of the thermocouples.

SAMPLE PREPARATION AND EXPERIMENTAL PROCEDURE

The soils which were investigated were from the northern region of New Zealand and were derived from an arkose. The three discussed in this work vary in stage of maturity; thus profile no. 1 is immature, profile no. 3 is a mature podzol, and profile no. 2 occupies an intermediate position.

The precise localities are: Profile no. 1—Whangarei County, Opuawhanga Survey District, 1½ miles north of Tutukaka on the Tutukaka-Mata-

pouri bay road; Profile no. 2—Whangarei County, Opuawhanga Survey District, 2 miles northeast of Marua on Marua road; Profile no. 3—Whangarei County, Hukerenui Survey District, 2 miles northwest of Ruapekapeka trig. station 4.6 miles southeast of Kawa Kawa.

These soils were subjected to successive treatments with 20 volume hydrogen peroxide to remove organic matter. In most cases two treatments sufficed, but in some rare cases not even 100 volume peroxide would remove the last traces of humic material. The soils were dispersed by shaking in a reciprocating shaker, using ammonium hydroxide as a dispersant. After dispersion, mechanical analysis of the samples was carried out prior to their separation by sedimentation and centrifugal means. The particle size diameters separated were: sand 2 mm-0.02 mm; silt 0.02 mm-0.002 mm; clay $<$ .002 mm.

The clay fractions were coagulated from suspension by lowering the pH to about 6.0 and adding a little A.R. sodium chloride. Excess soluble salts were washed from the clays by successive washing with distilled water, using centrifugal means to hasten settling. When chloride could be shown to be absent in the washings, the clays were dried using successively stronger alcohol washings, commencing at 15% and ending with absolute alcohol. To hasten drying several subsequent washings with acetone were given. This last also prevented the clay from drying as a hard cake, and usually a fairly powdery material resulted on drying the clay-acetone suspension. Silt fractions were also dried in a similar manner, but sand fractions were dried from water in an oven at 105° C.

It was found that after a little practice similar weights could be tamped into the sample holes of the thermal analysis block, provided the material remained the same. In all cases the amount of material used was weighed and a constant packing tightness was employed rather than a set weight. The effect of packing upon thermal curves has been commented upon by various workers. Thus Gruver (1948) concluded, using the same weight of sample, that the effect of packing on the type and area of the thermal curve was zero, but noted that texture could influence the reaction slightly. Schafer and Russell (1942) found that if the sample holes were not completely filled a drift of the galvanometer occurred, and that tight packing appeared to increase the area of the curve. Whitehead and Breger (1950) packed to a constant tightness of 530 psi using special tools; these workers used very small weights of material, and therefore packing could become an important factor.

As some specimens were obtainable only in very small amounts, the effects of dilution with calcined alumina were studied, and also the relationships between two methods of dilution. Thus one specimen, the clay fraction of profile 1 at a depth of 20-26 inches, was taken in various amounts. In one set of experiments the material was tamped into the sample hole and the remaining gap filled with calcined alumina. In the second set of experiments the material was tamped between alumina. The two graphs are reproduced in figure 2. For the second set of experiments there is a greater amount of reactive constituent about the thermocouple for similar weights, especially at low values, than in the first series. As a consequence the apparent energy

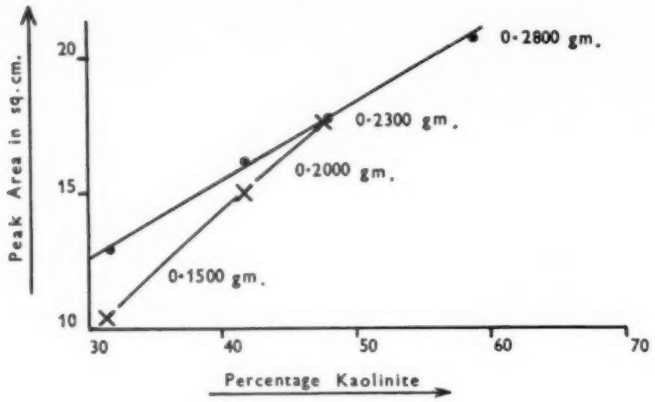

FIG 2

Peak area (570° endothermic) variation with sample dilution

• = Sample packed between Al_2O_3 × = Sample packed under Al_2O_3

intake is greater for the second series, and larger areas result. Schafer and Russell (1942) found a similar effect with kaolinite-halloysite mixtures diluted with alumina when somewhat similar experiments were conducted. Whitehead and Breger (1950) noted maximum effectiveness when the sample was packed about the thermocouple junction. Therefore, if dilution of a sample is necessary due to too violent a reaction, caking effects on heating, lack of material, etc., care must be taken to dilute the sample in a constant fashion, or quantitative measurements may become meaningless. It will be noticed that the curve for samples packed under alumina is curved whereas that for samples between alumina is straight. Perhaps in this may lie the explanation of the differing views upon whether weight:area curves are straight or sigmoidal. But this would need proof from other samples before being accepted. On the surface, it seems a possible explanation, and, in fact, Wittels (1951) has shown marked departure from linearity in weight:reaction area curves, with variation in mass of reactive constituent.

The relationship between the three differential thermocouple groups was established by using the clay fraction of profile 1, depth 20-26 inches, in duplicate experiments. The areas of the circa 570° C. endothermic peaks were obtained by a planimeter, and the line enclosing the curve was taken as the straight line joining the two points where the curve departs from a steady unidirectional tendency. These points are readily obtainable by laying a straight edge along the photographic record. They are quite arbitrary but they do serve as standard points, and the areas so measured are reproducible with great accuracy. Using the averaged values for the different thermocouple groups, a factorial arrangement was arrived at, and by using the requisite factor a sample run in, say, thermocouple group no. 3 could readily have its curve area converted in terms of thermocouple group no. 2.

TABLE 1

Chemical Analyses of Clay and Silt Fractions

Profile no. and depth in inches	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MnO	MgO	CaO	K_2O	Na_2O	Ign. Loss	Total
					CLAYS						
No. 1 0-2	46.10	1.66	25.08	9.70	0.06	1.26	0.52	0.96	0.08	15.20	100.62
8-12	48.23	1.45	24.29	9.78	0.01	0.72	0.31	0.68	0.09	14.23	99.79
20-26	46.96	2.71	23.00	12.52	0.05	0.69	0.60	0.41	0.04	13.72	100.70
66-72	41.16	1.30	27.31	12.89	0.01	0.21	0.08	0.13	0.09	16.10	99.28
156-162	40.97	1.50	28.34	11.03	0.06	N.D.	0.29	0.34	0.03	16.82	99.38
No. 2 0-4	44.36	1.50	29.20	6.84	0.02	1.56	0.28	0.44	0.34	16.62	101.16
29-32	38.18	1.69	28.97	13.14	Ab.	0.24	0.28	0.47	0.26	16.84	100.07
No. 3 12-14½	37.95	2.74	21.61	18.25	Ab.	0.30	0.45	0.20	0.18	18.40	100.08
24-28	36.58	1.66	28.86	14.36	Ab.	0.16	0.22	1.63	0.26	15.80	99.53
					SILTS						
No. 1 0-2	71.48	0.66	10.53	5.22	0.04	0.23	0.65	0.48	0.24	10.14	99.67
8-12	80.62	0.73	7.07	4.22	0.01	0.03	0.59	0.37	0.27	6.04	99.95
20-26	75.31	0.73	10.71	5.62	0.01	0.20	0.35	0.36	0.20	6.68	100.17
66-72	52.86	1.11	24.31	8.20	0.01	0.28	0.56	0.30	0.11	12.54	100.28
156-162	48.47	1.30	25.57	8.79	0.06	0.12	0.15	0.48	0.14	14.26	99.34
No. 3 0-6	95.91	0.73	0.50	0.28	Ab.	0.09	0.30	0.19	0.18	1.43	99.61
7-9	96.85	0.48	0.61	0.31	Ab.	0.08	0.34	0.09	0.10	0.87	99.73
9-11½	97.07	0.65	0.77	0.34	Ab.	0.10	0.23	0.14	0.14	0.80	100.24
12-14½	90.97	0.64	2.56	3.14	Ab.	0.13	0.26	0.07	0.08	2.36	100.21
24-28	49.70	0.41	30.29	5.86	Ab.	0.06	0.12	0.66	0.16	13.45	100.71
42-48	48.51	0.89	30.56	5.79	Ab.	0.14	0.11	1.72	0.23	12.85	100.80

The efficiency of the thermocouples was checked from time to time, using the same standard sample mentioned above. Thermocouple replacement, due to embrittlement after prolonged use, did not necessarily change the areas (and therefore the factors) very greatly, but the size of the nickel sheath on the thermocouple must be rigidly controlled, or different heat absorption rates by thermocouple junctions result, and in such cases the areas can vary by about 20%.

TABLE 2

Thermal Analysis Data

Profile no. and depth in inches	Weight taken	Area of endothermic peak in sq. cm.	Observed temperature of peak.	Area of endothermic peak corrected to 0.2800 gm.	Al_2O_3%	Al_2O_3% converted to kaolinite%	Number used in figure 3.
			CLAYS				
No. 1 0-2	0.2800	22.4	572° C.	22.4	25.08	63.3	1.
"	"	22.5	570	22.5			
8-12	"	20.85	572	20.85	24.29	61.5	2.
"	"	20.25	570	20.25			
20-26	"	20.7	572	20.7	23.00	58.3	3.
"	"	20.7	572	20.7			
66-72	"	23.2	589	23.2	27.31	69.1	4.
"	"	23.4	578	23.2			
156-162	0.2404	23.4	578	27.3	28.34	71.7	5.
	0.2300	22.8	580	26.8			
No. 2 0-4	0.2306	21.85	583	26.5	29.20	73.9	6.
	0.2300	21.7	589	26.4			
29-32	0.2300	22.15	578	27.0	28.97	73.3	7.
		22.65	589	27.6			
No. 3 12-14½	0.1860	11.5	552	17.3	21.61	54.7	8.
	0.1900	11.2	547	16.5			
24-28	0.2042	19.05	578	26.1	28.86	73.1	9.
	0.2100	19.3	572	25.8			
			SILTS				
No. 1 0-2	0.3000	12.2	540 & 572	11.4	10.53	26.7	10.
8-12	0.3500	8.1	540 & 572	6.5	7.07	17.9	11.
20-26	0.3300	11.7	547 & 572	9.9	10.71	27.1	12.
66-72	0.3000	29.8	565	27.8	24.31	61.5	13.
156-162	0.2540	24.1	565	26.6	25.57	64.7	14.
No. 3 0-6	0.3710	1.55	498 & 570	1.2	0.50	1.3	15.
7-9	0.3920	1.2	498 & 570	0.9	0.61	1.3	16.
9-11½	0.3800	2.2	498 & 570	1.6	0.77	2.0	17.
12-14½	0.3500	4.0	521 & 575	3.2	2.56	6.5	18.
24-28	0.2500	27.2	572	30.4	30.29	76.7	19.
42-48	0.2580	30.2	575	35.0	30.56	77.4	20.

The three profiles had selected clay fractions analyzed by X-ray powder diffraction methods. The lines present fell into a general kaolinite-quartz pattern, with one or two very weak or enhanced lines which could be attributed to other oxides reported on later. Selected clay fractions were chemically analyzed; their results appear in table 1. The thermal curves for the series show no signs of other clay minerals such as illite or montmorillonite, and therefore it seems highly reasonable to place all the alumina as kaolinitic alumina. This is further substantiated by the chemical analyses in table 1. Chemical analysis of various pure kaolinites has revealed that the percentage of alumina in the molecule varies (Ross and Kerr, 1931). In this investigation, the idealized lattice value of 39.5% Al_2O_3 has been chosen, and it will be seen that good agreement has been obtained.

In the thermal curves there are two indentations, both being the characteristic kaolinitic pattern, viz. the large endothermic with peak temperatures at about 570-580°-C., and the exothermic with peak temperatures varying considerably about a temperature of 950°. It is inadvisable to use this latter peak in quantitative estimations, for it has been shown by various workers that the iron content alters the peak temperatures and lowers the areas of such curves (Caillère and Hénin, 1947; Grim and Rowland, 1942; Saunders and Giedroyc, 1950). Attention has therefore been confined to the endothermic peak.

Taking the ideal value of 39.5% Al_2O_3 in kaolinite, the alumina figure obtained by chemical analysis (table 1) is converted to kaolinite percentage, and this figure is plotted against the corresponding area of the endothermic peak for that sample. The various data relating to percentage alumina and kaolinite and to the thermal curves have been tabulated in table 2. The remaining silica in the chemical analysis, after sufficient has been taken for kaolinite, would be quartz.

DISCUSSION OF RESULTS

Because of voltage fluctuation of the power supply, the energy input into the furnace was not always the same, hence the variation of peak temperatures on duplicate samples of the same material (table 2). This fluctuation does not affect the peak areas (Speil et al., 1945), and the agreement of these between duplicates is excellent, when the various inherent difficulties of area measurement are considered. It will be noticed, however, that the peak temperature rises with the rise in percentage of kaolinite present, and this property gives therefore an approximation of the amount present. The weights of sample which fit into the holes also reflect the percentage kaolinite in the samples. Thus the maximum area of endothermic peak corresponds with a value of about 0.21 gm; with decrease in percentage kaolinite and therefore decrease in area of the endothermic peak, the weights needed to fill the sample hole rise. This is an expression of the differences in specific gravity and specific volume between kaolinite and quartz. There is one exception to this rule, namely profile 3, depth 12-14½ inches, clay, for this sample contained light organic matter, which could not be removed by the hydrogen peroxide treatment, and therefore the resultant specific gravity is lower than

it should be for a simple mixture, and small weights fill the sample hole. As the percentage of kaolinite falls, the quartz peak becomes first of all just discernible as a slight indentation on the up-slope of the kaolinite peak. With a smaller percentage it becomes more visible, and eventually at a very low percentage, less than about 18%, the peak divides into two, and at a value less than about 9% kaolinite there are two well-separated curves.

In plotting the graphs in figure 3 it was necessary to compare a constant weight of sample, and therefore the areas obtained from the graphs have

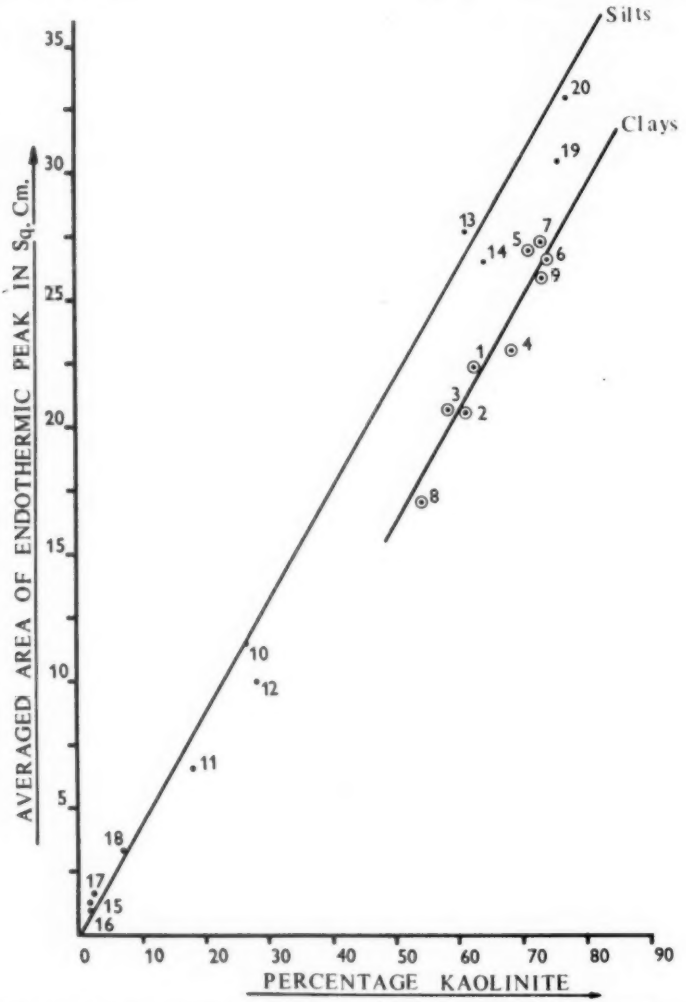

Fig. 3. Relation between endothermic peak area and percentage kaolinite for silts and clays.

been corrected to a value of 0.2800 gm. This value is arbitrary and was chosen because it is an average weight for these and other clay samples investigated. The validity of this correction finds substantiation in the graph of samples of differing weights packed between alumina and shown in figure 2.

The agreement among the clays plotted in figure 3 is surprisingly good when consideration is taken of the various inherent difficulties of the method. Furthermore, some samples such as profile 3, depth 12-14½ inches, clay, contained organic matter which even 100 vol. H_2O_2 would not remove, and the exothermic dome caused by the oxidation of this material interferes with accurate measurements of the kaolinite endothermic peak area. For the accurate quantitative determination of such contaminated samples, either a vacuum or inert atmosphere is required in the furnace; with the application of such apparatus to the problem, the scatter observed in figure 3 would be much reduced.

Agreement among the silt fractions is not so marked. The reason here is found if attention is directed to the alkali figures for these samples in table 1. It will be observed that the alkali contents are, generally speaking, much higher than for the clays. Consequently, some portion of the alumina which has been calculated as kaolinitic alumina must be in combination with the alkali as an alumino-silicate. It is for this reason that scatter is more pronounced, and also that the graph has been placed in a position which is not the most geometrically advantageous if the points are taken by themselves and alkali contents are neglected. When it is realized that 1% of Na_2O and/or K_2O will utilize approximately 2% Al_2O_3 in feldspar or micaceous structures, and that this in turn corresponds to an amount of approximately 5% kaolinite which should be subtracted from the calculated amounts of figure 3 and table 2, the scatter is readily explained. The impurity present in these samples is probably either feldspar or the sericitic decomposition product of feldspar, but positive data as to which is present is lacking.

Direct agreement between X-ray powder photographs, thermal analysis (table 2), and chemical analysis (table 1) is exhibited by a consideration of samples no. 1, depth 20-26 inches, clay, and no. 2, depth 29-32 inches, clay. The line strengths of these and pure kaolinite and pure quartz are tabulated in table 3.

Taking the two samples, calculating all the alumina as kaolinite, and allowing the ideal value of 39.5% Al_2O_3 to 46.5% SiO2, the amounts of SiO_2 needed for the kaolinite molecule can be calculated and the remainder placed as quartz.

Sample	Total Al_2O_3	Total SiO_2	SiO_2 needed for Ka. lattice	Remainder
No. 1, 20-26 inches, clay	23.00	46.96	27.07	19.89
No. 2, 29-32 inches, clay	28.97	38.18	34.10	4.08

In the powder photographs, which were obtained keeping conditions as constant as possible, the values obtained by chemical and thermal analysis are closely parallelled. In no. 1, depth 20-26 inches, clay, almost all the quartz lines are present, whereas in no. 2, depth 29-32 inches, clay, only the very

TABLE 3

Line Strengths of X-ray Powder Photographs (in Ångstrom Units)

Quartz	Kaolinite	Strength	Profile 1, depth 20-26 inches clay	Profile 2, depth 29-32 inches clay	Unmatched Lines
	7.19	s	m	s	
	4.41	ms	m	ms	
4.28		s	m		
	4.16	ms	w	s	
	3.57	s	m	ms	
3.35		vs	s	ms	
			vw	w	2.68
	2.56	ms	m	ms	
	2.49	ms	m	vw	
2.46		m	w	w	
	2.34	ms	vw	w	
2.28	2.29	m, m	w	vw	
2.23		w	w	w	
	2.19	vw		vw	
2.13		m	vw		
1.97	1.99	m, m	vw	vw	
	1.89	vw		w	
1.81		s	ms	w	
	1.78	m		vw	
			w	m	1.70
1.67	1.66	w, ms	w	vw	
1.54		s	m	w	
	1.49	ms	m	m	
1.45	1.45	w, vw	m		
1.38		s	w		
1.37		s	w		
1.29		m	vw		
1.25	1.25	m, vw	w		
1.23	1.23	w, vw	vw		
1.20		ms	w		
1.18		s	vw		
1.15		m	w		
1.08		ms	w		
1.05		m	w		
1.03		m	w		
1.01		m	w		
0.988		m	w		
0.986		m	vw		

Intensities: s = strong, m = moderate, w = weak, v = very.

strongest of the quartz lines appear (see table 3). The lines appearing at 2.68 Å and 1.70 Å are placed as due to hematite, for there is a large amount of iron oxide in the samples, as shown by chemical analysis (table 1). The thermal curves in the 290-350° region would tend to substantiate this result. It is believed that the 1.89 Å kaolinite reflection, very faint in pure kaolinite

and yet appearing slightly stronger in no. 2, depth 29-32 inches, clay, is due to anatase, and this mineral would also reinforce the 1.70 Å reflection placed as a hematite reflection. Although the titanium content is low (1.69%) it might be expected to show, for titanium is a heavy atom and X-ray exposures were for 12 hours. Nagelschmidt (1949) has recorded anatase from sedimentary kaolins. The high iron content of the samples, with appearance of only the very strongest hematite lines, points to this mineral's being in a very fine state of division and practically amorphous, a condition frequently encountered in soil clays (Hendricks and Alexander, 1939).

The two different curves obtained for silts and clays show quite clearly that in evaluation of minerals in soil clays by thermal analysis an individual curve must be established for each fraction. Agreement between fractions of the same size and from different depths of the same profile is good and, in the case investigated, so also is correlated between three profiles, in different states of maturity and weathering but from the same parent material. The last is an important conclusion, for if it can be shown to hold for other samples, then standardization of the instrument need only be effected for each soil group and fairly rapid measurements might then be undertaken.

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DISCUSSION

EFFECT OF CHANGE OF ORIGIN ON MEAN AND VARIANCE OF TWO-DIMENSIONAL FABRICS

F. CHAYES

ABSTRACT. The mean and variance of two-dimensional cyclical data are sensitive to the choice of origin. The strength of this effect and the mean from which the variance will be least can be determined prior to calculation of the variance.

Mr. Jizba's objection (1953) to the Griffiths-Rosenfeld (1953) test of departures from isotropism is well taken, and Dr. Griffiths' reply (1953) does not meet it. The mean and variance of two-dimensional cyclical data, like azimuths or inclinations, *are* sensitive to the choice of origin. This will usually be true of the related population parameters as well. Mr. Jizba contents himself with an analytical expression for the special case in which only one datum is shifted from the low to the high end of the sample distribution, but the general relation is not difficult to derive.

Figure 1 shows a hypothetical frequency curve in which two choices of origin are available; one at O, the other at A. In the first case the distribution extends from O to R and in the second from A to $(R + A)$, where R is, in our case, 180°. In the discussion which follows, readings less than A will be indicated by subscript a, those between A and R by subscript b. The

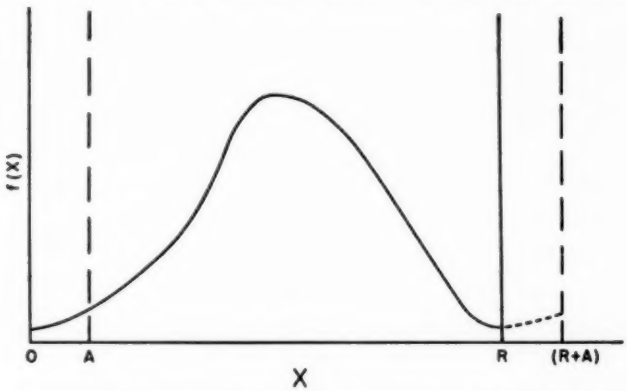

Fig. 1. Continuous cyclical distribution with two choices of origin.

mean and variance calculated from O as origin will be indicated by subscript 1, those formed from A as origin by subscript 2. Finally, n_a refers to the number of readings less than A, n to the total number of readings, and k_a to the fraction n_a/n.

The means calculated from the two origins are obviously

$$\bar{x}_1 = \frac{1}{n}\left\{S(X_a) + S(X_b)\right\} \qquad (1)$$

and

$$\bar{x}_2 = \frac{1}{n}\left\{S(X_a + R) + S(X_b)\right\} = \bar{x}_1 + k_a R \qquad (2)$$

The sums of squares are

$$S_1^2 = S(X^2) - n\bar{x}_1^2 = S(X_a^2) + S(X_b^2) - n\bar{x}_1^2 \quad (3)$$

and

$$S_2^2 = S(X_b^2) + S\left\{(X_a + R)^2\right\} - n\bar{x}_2^2 \quad (4)$$

Subtracting (3) from (4) we have

$$S_2^2 - S_1^2 = S\left\{(X_a + R)^2\right\} - S(X_a^2) - n\bar{x}_2^2 + n\bar{x}_1^2 \quad (5)$$

and after expansion and rearrangement this reduces to

$$S_2^2 - S_1^2 = 2RS(X_a) + n_a R^2 - nR^2 k_a^2 - 2nRk_a\bar{x}_1 \quad (6)$$

Ignoring the correction for finite sample size, we divide by n to obtain the difference between the two calculated variances

$$s_2^2 - s_1^2 = \frac{1}{n}(S_2^2 - S_1^2) = \frac{2}{n}RS(X_a) + k_a R^2 - R^2 k_a^2 - 2Rk_a\bar{x}_1 \quad (7)$$

Substituting $n = n_a/k_a$ in the first term of (7) gives

$$s_2^2 - s_1^2 = 2Rk_a\frac{S(X_a)}{n_a} + k_a R^2 - 2Rk_a\bar{x}_1 - R^2 k_a^2 \quad (8)$$

$$= 2Rk_a\left\{(\bar{x}_a - \bar{x}_1) + \frac{R}{2}(1 - k_a)\right\}$$

where $S(X_a)/n_a$, which is the mean of the values lying between the two origins, is denoted by $\bar{x}_a$. We may thus define an easily calculated "variance indicator"

$$I_v = k_a\left\{(\bar{x}_a - \bar{x}_1) + \frac{R}{2}(1 - k_a)\right\} \quad (9)^1$$

[1] If the variance is defined as $S(X - \bar{x})^2/(n - 1)$, as is usual in practical work, the k_a outside the bracket in (9) should be replaced by $n_a/(n - 1)$.

whose sign indicates the sense and whose size is proportional to the difference between variances calculated from any two origins. The variance difference in any particular case is, of course, $2RI_v = 360I_v$. It is both curious and convenient that the locations of the critical origins and the actual size and sense of the variance difference between them can be obtained without knowledge or calculation of either variance. The procedure is as follows:

A. Calculate $\bar{x}_1$ from any origin.

B.1 (Grouped data). Evaluate I_v stepwise for origins taken at the lower bounds of successive classes.

B.2 (Ungrouped data). Evaluate I_v stepwise for origins taken at equal intervals over the range.

C.1 A minimum variance origin is one from which I_v assumes its largest negative value.

C.2 A maximum variance origin is one from which I_v assumes its largest positive value.

C.3 The maximum variance difference which may be generated by choice of origin is

$$2R \left| I_{vc,1} - I_{vc,2} \right|.$$

In the example given by Mr. Jizba the first origin was 90°, and the information required to locate origins of maximum and minimum variance is shown in table 1. $s^2_{90} = 2755.39$ for the original arrangement, giving

TABLE 1

Variance Indicators, Data of Jizba

(Symbols as defined in the text)

A	X_a	$Sf(X_a)$	$S\{X_a f(X_a)\}$	$\bar{X}_a$	$(\bar{X}_a - \bar{X}_1)$	k_a	$1 - k_a$	$90(1 - k_a)$	I_v*
110	100	14	1400	100.00	−79.60	.14	0.86	77.40	−0.311
130	120	26	2840	109.24	−70.36	.26	0.74	66.60	−0.9875
150	140	32	3680	115.00	−64.60	.32	0.68	61.20	−1.0989
170	160	39	4800	123.09	−56.53	.39	0.61	54.90	−0.6421
190	180	55	7680	139.63	−39.97	.55	0.45	40.50	+0.2944
210	200	68	10280	151.18	−28.42	.68	0.32	28.80	+0.2610
230	220	77	12260	159.72	−20.38	.77	0.23	20.70	+0.2489
250	240	91	15620	171.65	−7.95	.91	0.09	8.10	+0.1379
270	260	100	17960	179.60	0	1.00	0	0	0

*Calculated for $V = S(X - \bar{X})^2/(n - 1)$.

a standard deviation of 52.59°. For $A = 150°$, the new origin chosen by Jizba, table 1 gives $I_v = -1.099$, so that from equation (8)

$$s^2_{150} = 2755.39 - (1.099)(360) = 2359.75$$

and s_{150} is, accordingly, 48.58°.

It is easily shown that the variance of the rectangular parent taken as the model of isotropism is independent of the choice of origin. In such a parent

$$\kappa_a = \frac{A}{R}, \quad \mu_a = \frac{A}{2}, \quad \mu_1 = \frac{R}{2},$$

and substituting these values in equation (9) we have at once that $I_v = 0$. So far as I know, κ_a and μ_a cannot be so defined over the full range of any other distribution; if follows that in general $I \neq 0$, so that variance *must* be sensitive to the origin. Thus if we choose a "natural" origin, as Mr. Jizba suggests, or a "unique" one, as Professor Griffiths prefers, we cannot hope to use the size of the variance as a decisive indication that no orientation exists. At most we shall only be able to decide whether the variance *calculated from some particular origin* is or is not significantly small. Failure to establish orientation is thus essentially meaningless. If the statistics are calculated from a minimum-variance origin, however, the test is interpretable whatever its result, for if it fails from a minimum-variance origin it will also fail from every other origin.

The problem is evidently much more complex than most of us had supposed, and I am aware that this note raises more questions than it answers. Differences between mean directions will most frequently appear significant if each mean and its accompanying dispersion are calculated from a minimum-

variance origin. Such an origin will obviously be the most efficient whenever it is important to focus attention on (or avoid overlooking) small differences in mean directions. But for every practical situation in which we are anxious to avoid errors of the first kind, there will be another in which avoidance of error of the second kind is at a premium.

There is one final complication which, in a sense, undoes all the preceding work. It seems fairly clear on intuitive grounds that, where the scatter is large enough so that we wonder whether an orientation actually exists, there will be only one minimum variance, and thus only one mean from which the variance is a minimum. In samples of finite size, however, there will be a range of origins, *any one of which will yield this same mean and variance.* From equation (2) it is clear that as long as $n_a = 0$, so that the change of origin does not shift any of the observations from one end of the range to the other, the mean will be unaffected. And if $n_a = 0$, k_a is also 0 and, from equation (9), $I_v = 0$. The stronger the orientation, the broader will be the region within which any point chosen as origin will yield the mean direction having minimum variance. Thus, the surer we are that an orientation exists, the less significance—geological or otherwise—attaches to the origin from which it has been calculated (or graphed).

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REVIEWS

Physical Geology; by L. Don Leet and Sheldon Judson. P. ix, 466; 354 figs. New York, 1954 (Prentice-Hall, Inc., $9.00).—A major problem facing the author of a textbook such as this one is that rarely do students at freshman level have sufficient background in atomic theory and chemistry for a thorough presentation of the structure of minerals and rocks, and of the processes that act upon them. To present selected material from these related sciences and yet retain the discipline of geologic thinking is a delicate matter of judgment. The author must go deeply enough to give an understanding but not so deeply as to be overwhelming or diverting. The present book is generally successful in this difficult task.

With an eye to the teaching schedule of a one-semester course, sixteen chapters have been planned. The first three deal with materials; then follow eight chapters on processes of gradation; and diastrophism, vulcanism and mineral deposits are at the end. In a departure from previous textbooks, the chapter on the age of the Earth and its place in the universe appears near the end of the book.

As common in newly written textbooks, particularly those by more than one author, the style and pace are somewhat uneven. The chapters on "Material of the Earth," and "The Earth's Age and Place in the Universe," are all that one could ask of a text—if the teacher wants this much detail. Unfortunately, some parts are not up to these standards. The chapter on "Igneous Rocks" for example is an excellent summary of current concepts in mineralogy and petrology, but the very wealth of material detracts from the straightforward presentation desirable in an elementary text. The first two-thirds of the chapter is devoted to a discussion of minerals, and particularly to the structure of silicates, to a degree of complexity that seems undesirable if the book is to be used by students lacking a basic knowledge of chemistry and physics. The last third of the chapter, actually concerned with igneous rocks, is too brief a treatment to deal adequately with such concepts as isomorphous and discontinuous series, fractionation, metastable state, and solid solution. Such a concentration of new terms and ideas will be confusing if not downright baffling to most beginning students.

The chapter on running water leans too heavily on one or two technical studies without pointing out the application. The student may well ask, "Well, what of it?" The discussion of the cycle of erosion might at least point out the two rival schools of thought. In the chapter on ground water, discussion of the yield of a well based on Darcy's law raises the student's interest only to disappoint him in the last sentence, where he finds: "In actual practice, the great difficulty in applying this formula is the determination of the hydraulic gradient." Elsewhere he finds that one of the conditions which are said to be required for an artesian water system is an impermeable layer below the aquifer as well as above it. A cap-rock alone is sufficient. At the beginning of the chapter he is told that "part of the surface water soaks directly into the ground and part is fed into the ground from lakes and streams." This would mislead a beginner at this stage of his thinking and should be postponed to the technical discussion of recharge.

The discussion of orogeny and of the Earth's interior is somewhat dogmatic in ruling out the convection current hypothesis and in a wholehearted acceptance of the cooling-contraction hypothesis of orogeny, though there is certainly no general agreement on either matter among geologists and geophysicists.

The illustrations for the most part are plentiful, new, and excellent. Unfortunately, many of them are not referred to in the text. When, as often happens, these illustrations follow pertinent text material by a page or more, the reader is not aware of them and they lose much of their usefulness. Diagrams are well done except where vertical exaggeration is too great as in figures 7-9 and 7-17. An extensive glossary and appendix will be useful to serious students. The printing is clear in the modern two-column page, but many of the halftones have been damaged by poor press work.

This book becomes a third addition to the crop of beginning texts that make an affirmative effort to base the discussion on the most recent ideas in physics and chemistry. Each of these three will find enthusiastic adherents. In fact, we two reviewers do not agree entirely.

PAUL MACCLINTOCK
J. C. MAXWELL

Volcanoes as Landscape Forms. 1st ed. revised 1952; by C. A. COTTON. P. 416; 223 figs. New York, 1953. (John Wiley & Sons, Inc., $9.00).—Because volcanoes, unlike most topographic features, are constructional rather than erosional forms, this book differs refreshingly from most geomorphic books, emphasizing the constructional processes of eruptive volcanism rather than erosional processes. The effects of erosion are not overlooked, but the majority of the book falls into two parts: the great variety of types and processes of eruption that occur as a result of differences among magmas in gas content, in chemistry of the non-gaseous constituents, in temperature, in size and shape, and in environmental conditions; and secondly, the great variety of major and minor topographic features formed by these varied types of eruption.

The revised edition now made available in this country is essentially a reprinting of a book originally written in 1944 and published in New Zealand and Great Britain. The revisions involved are not extensive—deletion of a figure or two, insertion of several quotations from papers not originally cited—and the work is rightly not considered a second edition.

Admirers of Professor Cotton's usually lucid and authoritative writing are likely to be disappointed in this volume, which is made rather heavy reading by its constant quotation and appeal to authority. The writer appears to have felt self-conscious about stepping from his own sphere of specialization, landforms, into the field of volcanism, and it is a rare page that does not have from two to six footnotes, chiefly references to the sources of statements quoted. A more straightforward presentation of the facts, even at the risk of a possible error here and there, would have made the book more readable. Nevertheless, it is a valuable compilation of information that will undoubtedly be known for many years as the standard reference work on volcanic terranes.

CHARLES R. WARREN

The Charnockite Problem; by C. S. PICHAMUTHU. P. ii, 179, 1 map. Bangalore, 1953 (Mysore Geologists' Association, Rs. 7-8 (about $1.50)).—All geologists interested in igneous and metamorphic petrology or, to put it more broadly, plutonic geology, will welcome this outstanding review and critical synthesis of the geology and genesis of charnockites and related rock series. In the first 46 pages Dr. Pichamuthu gives a concise account of the nomenclature, mineralogy, petrography, mode of occurrence, and economic aspects of charnockites and related rocks. Under the heading Distribution is a catalogue of charnockite localities in India, followed by a geographic listing of localities throughout the world in which charnockites or rocks of charnockitic affinities have been reported. Dr. Pichamuthu judiciously founds this essentially descriptive part of the book on the classic work of Sir Thomas Holland and then shows the modifications and extensions wrought upon it by later workers.

The ideas concerning the origin of charnockites that have arisen out of the investigations of many workers in India are then set forth. First the arguments and nature of the evidence favoring a magmatic origin are given, and then the arguments and evidence for a metamorphic origin are summarized. This is done with such scholarly objectivity that Dr. Pichamuthu's own point of view remains enigmatic while he effectively conveys to the reader a more thorough insight into the attack that has been made on the charnockite problems of India.

The section of the book that will probably be of greatest general utility to geologists not directly concerned with India is titled "History of Research Outside India." In this chapter some 50 contributions to the charnockite and related problems are summarized in chronological order, beginning in 1903. With masterful conciseness the important ideas and relationships are abstracted from this mass of literature and brought to focus on the charnockite problem, and in the process a great deal of light is thrown on related problems of metamorphic facies, enderbites, mangerites, granulites, and ideas regarding plutonic processes in general. At the same time I am afraid a rather harsh and not too flattering light is thrown on the mental processes of geologists. The reader is repeatedly struck with the way in which exactly the same facts have been used by different geologists to reach diametrically opposed conclusions. Again and again we are solemnly assured, for example, that because rocks with charnockite associations encompass a broad range of bulk chemical compositions, all of which show marked mineralogical and textural resemblances, a common, co-magmatic origin by differentiation is indicated. Other writers will use the same facts to argue a metamorphic origin as representatives of a common facies. One is left with the impression that there is hardly a feature of the charnockite series, no matter how ambiguous it really is in the present state of actual knowledge of plutonic processes, that has not been dragged into the arena to bolster conflicting points of view. Amidst the dust and haze of argument Dr. Pichamuthu picks his way with scholarly detachment.

Finally, after a review and description of the charnockites of Mysore, which as Director of the Mysore Geological Department is Dr. Pichamuthu's

particular concern, a statement and discussion of Dr. Pichamuthu's own point of view is given. The chapter heading "Charnockites and Charnockites" is the clue to his approach. Dr. Pichamuthu's solution of the charnockite problem in India is complex and polymetamorphic. Charnockitic rocks originally came into existence in response to deep-seated and intense regional metamorphism of a terrain that included sediments, volcanics, and ancient granitic gneisses. After a period of relaxation of regional metamorphism during which basic dikes were intruded that sharply transect the metamorphic structures, a new period of strong thermal metamorphism began on a regional scale. This is attested to by the clouding of feldspars in the basic dikes over large areas. During this later metamorphism some charnockitic rocks were palingenetically mobilized, producing transgressive relationships and introducing charnockites into terrains of lower metamorphic rank.

By means of the synthesis very broadly sketched above, a number of the anomalies in charnockite relationships in India are resolved, but Pichamuthu is quick to point out that in the charnockitic series there may be a convergence of magmatic and metamorphic processes, so that in other parts of the world suites of charnockitic aspect may have been arrived at along different paths of metamorphic or magmatic activity.

This reviewer has only the highest admiration for the manner in which Dr. Pichamuthu has elucidated the charnockite problem and for his approach to a solution of the problem as it presents itself in India. Perhaps this is only because I have urged a polymetamorphic solution involving remobilization of an older sequence as an answer to some of the problems of the Adirondack region of New York where a rock series of charnockitic affinities has long been recognized. At any rate I feel that Dr. Pichamuthu has made an outstanding contribution to plutonic geology, and because it is both a review and a synthesis it will ease rather than add to the burden of literature in this field.

I can offer as adverse crticsm only a few rather carping comments. The most weighty is that an adequate map to serve as a guide to the discussion of the charnockite problem in India is lacking. The small index map that is appended does not show a fraction of the locality names that appear in the text, and to one unfamiliar with the detailed geography of India the welter of exotic names becomes most confusing. The discussion would have been further strengthened by a couple of additional maps showing the principal physiographic and tectonic units referred to and the distribution of the principal geologic terrains.

MATT WALTON

Rocks and Mineral Deposits; by PAUL NIGGLI. English translation by ROBERT L. PARKER. P. xiii, 559; 331 figs., 72 tables. San Francisco, 1954 (W. H. Freeman & Company, $12.00).—The German edition of Paul Niggli's *Rocks and Mineral Deposits. Volume I* (General Considerations), was pub-

lished in 1948 (reviewed in this JOURNAL, v. 247, no. 11, p. 831-832). An English edition now follows. That this is more than a mere translation is attested by Niggli in his preface, written the month before his death. Professor Parker was in daily contact with the author, and several additions and changes were made in preparing this new edition, notably the omission of the original Part IV on geophysics. Most of the illustrations have been reproduced unchanged, but English translations are provided in the captions where necessary. No literature references are given save for a selected bibliography at the end; nevertheless the book is of great value for advanced students of mineralogy and petrology for its insights into crystal chemistry, geochemistry, and rock fabrics.

JOHN RODGERS

Proceedings of the Southeastern Mineral Symposium, 1950: Techniques of Mineral Resources Exploration and Evaluation; PRESTON MCGRAIN, editor. Kentucky Geological Survey, Ser. 9, Special Pub. 1. P. 166; figs., 2 pls. Lexington, 1953.—In this volume are published the papers that were presented at a symposium under the chairmanship of V. E. Nelson, held at Lexington, Kentucky, in March, 1950. This symposium is the second of a series dealing with the geology of mineral deposits that has been held in the Southeastern States; the first was held at Knoxville, Tennessee, in 1949; later ones were held at Emory University, Georgia, at Roanoke, Virginia, and at Nashville, Tennessee. The informal organization sponsoring these meetings has subsequently evolved into the Southeastern Section of the Geological Society of America.

The present publication strikes a good balance between general or background papers, and papers on specific mineral deposits or mineral commodities. The general papers include accounts of the Coastal Plains (by W. H. Monroe), the Piedmont (by W. R. Brown), the Interior Lowlands (by C. W. Wilson, Jr.), and the Valley and Ridge province (by John Rodgers). The specific papers include reports on clays, artesian water, salt and sulphur, copper, coal, and fluorspar. To this reviewer, the most interesting general papers are those by Brown and Rodgers—partly because of the reviewer's own interest in the Valley and Ridge and Piedmont Provinces, and partly because the two papers contain much information that has not hitherto been published. Brown presents a geologic map, stratigraphic column, and structure section of the Lynchburg quadrangle, Virginia, an area which occupies a key position in the Piedmont province; in his text he discusses the relations of this quadrangle to the Virginia Piedmont as a whole. Rodgers elaborates on a thesis, briefly stated in several earlier papers, that the folding and thrusting in the Valley and Ridge province were confined to the sedimentary prism and did not involve the underlying basement.

The present volume is a worthy companion to the published proceedings of the first symposium,[1] but it probably will be the last of its kind. Some of

the papers given at the succeeding symposium at Emory University have been included in a "short contributions" volume of the Georgia Survey,[2] but not specifically in the form of a symposium volume. No plans have been made to print the proceedings of the succeeding symposia as unit volumes.

PHILIP B. KING

[1] F. G. Snyder, editor, 1950, Symposium on mineral resources of the southeastern United States, 1949 proceedings: Knoxville, Tenn., Tennessee Univ. Press.

[2] Garland Peyton, director, 1953, Short contributions to the geology, geography, and archaeology of Georgia, no. 2: Georgia Geol. Survey Bull. 60.

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ERRATUM

In the July number of this year the first three lines on page 445 are out of place. They belong on page 446 as lines 2, 3, and 4, between the first two printed lines of that page.

VOL. 252 No. 9, 1954

American Journal of Science

SEPTEMBER 1954

CONTENTS

FISH CREEK PHACOLITH, NORTHWESTERN NEW YORK ....*R. V. Dietrich* 513

SOIL TONGUES AND THEIR CONFUSION WITH CERTAIN INDICATORS OF PERIGLACIAL CLIMATE .....*Lynn A. Yehle* 532

ON THE ORIENTATION OF LAKE BASINS .....*D. A. Livingstone* 547

QUANTITATIVE DIFFERENTIAL THERMAL ANALYSIS OF SOIL CLAYS AND SILTS .....*R. J. W. McLaughlin* 555

DISCUSSION

EFFECT OF CHANGE OF ORIGIN ON MEAN AND VARIANCE OF TWO-DIMENSIONAL FABRICS .....*F. Chayes* 567

REVIEWS

Physical Geology; by L. DON LEET and SHELDON JUDSON .....*Paul MacClintock, J. C. Maxwell* 571

Volcanoes as Landscape Forms; by C. A. COTTON .....*Charles R. Warren* 572

The Charnockite Problem; by C. S. PICHAMUTHU .....*Matt Walton* 573

Rocks and Mineral Deposits; by PAUL NIGGLI. Translated by ROBERT L. PARKER *John Rodgers* 574

Proceedings of the Southeastern Mineral Symposium, 1950; Techniques of Mineral Resources Exploration and Evaluation; PRESTON MCGRAIN, *editor* *Philip B. King* 575

PUBLICATIONS RECENTLY RECEIVED 576

ERRATUM 576